

Env

CA20N
EV 665
1985
S 72

ISBN 0-7743-8212-0

Ann 85

Do not MF

C.1

**Air Resources Branch
Emission Technology and Regulation Development Section
Source Measurement Unit**

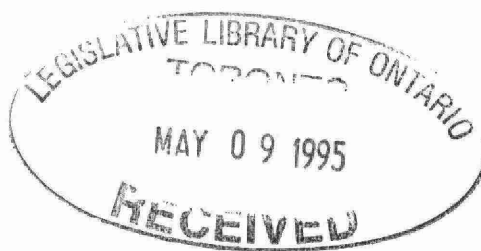
REPORT #ARB-54-83-ETRD

**STACK EMISSIONS FROM THREE LARGE SOURCES AT THE
TEXACO REFINERY IN NANTICOKE, ONTARIO**



Ontario Ministry of the Environment
880 Bay Street
Toronto, Ontario
M5S 1Z8

January 1985



Copyright Provisions and Restrictions on Copying:

This Ontario Ministry of the Environment work is protected by Crown copyright (unless otherwise indicated), which is held by the Queen's Printer for Ontario. It may be reproduced for non-commercial purposes if credit is given and Crown copyright is acknowledged.

It may not be reproduced, in all or in part, for any commercial purpose except under a licence from the Queen's Printer for Ontario.

For information on reproducing Government of Ontario works, please contact ServiceOntario Publications at copyright@ontario.ca

**STACK EMISSIONS FROM THREE LARGE SOURCES AT THE
TEXACO REFINERY IN NANTICOKE, ONTARIO**

BY

S. (Denis) Maftei

Air Resources Branch

Ontario Ministry of the Environment

Report Number ARB-54-83-ETRD

c 1983 Her Majesty the Queen by Right of Ontario

ACKNOWLEDGEMENT

The co-operation and efforts of R. Cameron, J. Logan and E. Hartt which were of great help and assistance in the planning, execution and reporting phases of this project are hereby gratefully acknowledged.

Stack sampling has been performed by Arthur Gordon Environmental Evaluators under subcontract to Beak Consultants Ltd.

Dr. B. Foster, of the Laboratory Services Branch, Ministry of the Environment, was responsible for the analytical work. His contribution was essential in the completion of the project and is hereby recognized.

Funds for this survey have been provided from the budget of the Ontario Ministry of the Environment Nanticoke Environmental Management Programme.

TABLE OF CONTENTS

	<u>Page</u>
1. Summary	1
2. Introduction	2
3. Description of the Refinery	6
3.1 Fluid Catalytic Cracking Unit CO Boiler	7
3.2 No. 1 Power Boiler	9
3.3 Sulphur Recovery Unit	10
4. Sampling Procedure	13
4.1 Total Particulate Matter	13
4.2 Sulphur Dioxide	15
4.3 Nitrogen Oxides	16
4.4 Hydrogen Sulphide	17
5. Discussion of Results	19
5.1 Fluid Catalytic Cracking Unit CO Boiler	19
5.1.1 Total Particulate Matter	19
5.1.2 Particle Size Distribution	20
5.1.3 Trace Element Analysis	20
5.1.4 Sulphur Dioxide	22
5.1.5 Nitrogen Oxides	22
5.2 No. 1 Power Boiler	24
5.2.1 Total Particulate Matter and Trace Metal Analysis	24
5.2.2 Sulphur Dioxide	25
5.2.3 Nitrogen Oxides	26
5.3 Sulphur Recovery Unit	26
6. Conclusions and Recommendations	28
BIBLIOGRAPHY	30
APPENDIX 1 - Production Data	
APPENDIX 2 - Laboratory Results	
APPENDIX 3 - Calibration Data	
APPENDIX 4 - Field Sheets	

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
FIGURE No. 1	Fluid Catalytic Cracking Reactor	8
FIGURE No. 2	No. 1 Power Boiler Schematic	11
FIGURE No. 3	Process Flow Diagram for Sulphur Recovery (Claus) Unit	12
FIGURE No. 4	Sampling Train for Particulate Matter	14
FIGURE No. 5	Sampling Train for Nitrogen Oxides	17
FIGURE No. 6	Particle Size Distribution of Particulate Matter Emitted by the Stack of the CO Boiler - Test 1	36
FIGURE No. 7	Particle Size Distribution of Particulate Matter Emitted by the Stack of the CO Boiler - Test 2	38
FIGURE No. 8	Particle Size Distribution of Particulate Matter Emitted by the Stack of the CO Boiler - Test 3	40

LIST OF TABLES

<u>Table</u>		<u>Page</u>
TABLE 1	Summary of Test Results Obtained at Three Major Stacks in the Nanticoke Refinery of Texaco	31
TABLE 2	Estimated Emissions from Major Exhaust Stacks at the Texaco Refinery in Nanticoke*	32
TABLE 3	Summary of the Particulate Matter Tests at the Stack of the CO Boiler	33
TABLE 4	Summary of the Results of the Particulate Sizing Tests at the Stack of the CO Boiler	34
TABLE 5	Particle Size Distribution of Particulate Matter Emitted by the Stack of the CO Boiler - Test No. 1	35
TABLE 6	Particle Size Distribution of Particulate Matter Emitted by the Stack of the CO Boiler - Test No. 2	37
TABLE 7	Particle Size Distribution of Particulate Matter Emitted by the Stack of the CO Boiler - Test No. 3	39
TABLE 8	Trace Elements Analysis Performed on Samples of Particulate Matter from the Stack of the CO Boiler (all weights are in milligrams)	41
TABLE 9	Trace Elements Distribution on the Plates and Filter of the Andersen Collector for Tests at the Stack of the CO Boiler (all weights are in micrograms)	42
TABLE 10	Concentrations of Trace Elements (ppm by weight) on the Plates and Filter of the Andersen Collector for Tests at the Stack of the CO Boiler	43

<u>Table</u>		<u>Page</u>
TABLE 11	Summary of the SO ₂ Tests at the Stack of the CO Boiler	44
TABLE 12	Summary of the NO _x Tests at the Stack of the CO Boiler	45
TABLE 13	Summary of the Tests Performed at the Stack of the CO Boiler	46
TABLE 14	Summary of the Particulate Matter Tests at the Stack of the No. 1 Power Boiler (Fuel: No. 6 Fuel Oil)	47
TABLE 15	Trace Elements Analysis Performed on Samples of Particulate Matter from the Stack of the No. 1 Power Boiler (all weights are in milligrams) (Fuel: No. 6 Fuel Oil)	48
TABLE 16	Trace Elements Concentration of Different Substances (Concentrations Expressed as ppm w).	49
TABLE 17	Summary of the SO ₂ Tests at the Stack of the No. 1 Power Boiler (Fuel: No. 6 Fuel Oil)	50
TABLE 18	Summary of the NO _x Tests at the Stack of the No. 1 Power Boiler (Fuel: No. 6 Fuel Oil)	51
TABLE 19	Summary of the NO _x Tests at the Stack of the No. 1 Power Boiler (Fuel: Refinery Fuel Gas)	52
TABLE 20	Summary of the tests performed at the Stack of the No. 1 Power Boiler	53
TABLE 21	Comparison of Emission Rates and Emission Factors (Calculated per mJ of Heat in the Steam Produced) for the two Boilers Sampled	54

Table

Page

TABLE 22	Summary of the SO ₂ Tests at the Stack of the Sulphur Recovery Unit	55
TABLE 23	Summary of H ₂ S Tests at the Stack of the Sulphur Recovery Unit	56

1. SUMMARY

During the week of 14th to 20th November 1982 three major stacks of the Nanticoke Refinery of Texaco Canada Inc. were sampled and analysed for their principal pollutants. Each source has been sampled three consecutive times. The numbers presented are averages of the results obtained in the three tests. The refinery operating personnel did their best to avoid major and unusual disturbances in the process during the test period.

The CO Boiler, which follows the Fluid Catalytic Cracking Unit, was of interest because of the significant contribution that the catalyst regeneration operation is expected to make to its emissions. This stack emits 10.67, 237.82 and 11.1 g/s of particulate matter, sulphur dioxide and nitrogen oxides (expressed as NO₂), respectively. Single point particle size distribution measurements have shown that the mean aerodynamic diameter of the particulate matter emitted into the atmosphere is in the range 2.2 to 2.4 microns.

The No. 1 Boiler is considered typical for all the other boilers and heaters of the refinery. It emits 0.995, 57.75 and 15.58 g/s of particulate matter, sulphur dioxide and nitrogen oxides (expressed as NO₂), respectively.

The Sulphur Recovery Unit was to be tested previously by Texaco and was included in this programme at Texaco's request. Its atmospheric emissions amount to 51.93 g/s sulphur dioxide and 2.42 mg/s hydrogen sulphide but it is to be noted that during the sampling period the sulphur production of the unit was only thirty-seven percent of its design capacity.

The results are summarized in Table 1.

2. INTRODUCTION

In order to develop an adequate atmospheric model for the Nanticoke area, the emissions of various contaminants released by the three major industrial units established in the zone - Ontario Hydro, Stelco and Texaco - had to be quantified.

In the case of the Texaco refinery, the most significant pollutant is "hydrocarbons" and several surveys have been conducted by personnel of the Ontario Ministry of the Environment (MOE), Air Resources Branch². These surveys resulted in final reports which quantified both hydrocarbon emissions³ and their concentration in the surrounding atmosphere⁴. Other pollutants, of relatively lesser significance but still important, are particulate matter, sulphur dioxide, and nitrogen oxides.

The main sources of particulate matter in the refinery are the exhausts of the Fluidized Catalytic Cracking Unit (FCCU) and the large process heaters and boilers. The same sources are also responsible for the bulk of the nitrogen oxides emissions.

Sulphur dioxide is released at the stack of the Sulphur Recovery Unit (SRU) and in all burning processes where the fuel contains significant amounts of sulphur.

It was intended to obtain representative data on total emissions of particulate matter, sulphur dioxide and nitrogen oxides at the Texaco Nanticoke refinery by testing selected sources in a carefully planned survey.

Table 2 summarizes emission estimates on the principal pollutants being released from the five major stacks of the refinery. The source of the different numbers in the table was the Environmental Approvals and Project Engineering Branch of the Ministry.

Based on the estimates of Table 2, there appeared to be no doubt that the major pollution sources were the Multiflue Stack and the Sulphur Recovery Unit. Among the different stacks in the Multiflue, the CO Boiler is the largest source while the FCCU Charge Heater and the Power Boiler are close seconds.

The selection of the No. 1 Power Boiler as a source representative of all the boilers in the refinery has been made at the suggestion of Texaco and was based on the ease of control that the refinery personnel has over this particular source.

By sampling the No. 1 Power Boiler (which can be fired with either No. 6 Fuel Oil or refinery fuel gas) while it was running on No. 6 Fuel Oil, we found the emission factor for this source under severe (i.e. high sulfur fuel) operating conditions.

The contribution of the FCCU to the total emissions from the CO Boiler is of particular interest. For nitrogen oxides, this contribution has been quantified by sampling both the CO Boiler and the No. 1 Power Boiler while they run on refinery gas fuel. The emission factor (for nitrogen oxides) found in the tests on the No. 1 Boiler has been used to deduct the contribution of supplementary fuel used in the CO Boiler. It was realized that the firing conditions in the two boilers were not identical and the procedure described above would not allow for the differences to be identified. However, under the existing conditions at the site (gases from the FCCU Regenerator enter the CO Boiler at very high temperature), and with the limitations of the commercially available sampling trains, it was decided that this was the most reasonable approach.

The sources which were considered to be the most significant for this survey were:

- 1) The FCCU CO Boiler Flue
- 2) The No. 1 Power Boiler Flue
- 3) The Sulphur Recovery Unit Stack.

The FCCU CO Boiler is unquestionably the largest contributor to the total particulate matter and sulphur dioxide emissions of the refinery. It also serves a "one of a kind" process and no accurate estimates could be made about its magnitude other than by direct stack sampling.

The No. 1 Power Boiler is important in terms of both particulate matter and sulphur dioxide emissions and it is one of the largest contributors to nitrogen oxide emissions. The results obtained in sampling it would be applicable to all the other process heaters and boilers in the refinery (the same fuel is being used for all of them).

The Sulphur Recovery Unit is again a "one of a kind" operation and although the responsibility for testing it originally resided with Texaco it has been included in this project at their request. Sulphur dioxide is the main contaminant under normal operating conditions but hydrogen sulphide levels would also be of interest in this case.

The following sampling and analysis have taken place

- a) The FCCU CO Boiler Flue has been sampled for
 - i) Total particulate matter
 - ii) Sulphur dioxide
 - iii) Nitrogen oxides

The additional fuel used by the boiler during the sampling was refinery fuel gas.

During the tests for total particulate matter, separate samples have been taken with an in-stack fractionating device (nine stage Andersen impactor) in order to determine the particle size distribution.

- b1) The No. 1 Power Boiler Flue has been sampled for:
 - i) Total particulate matter
 - ii) Sulphur dioxide
 - iii) Nitrogen oxides

while the fuel to the boiler was No. 6 Fuel Oil and
- b2) The No. 1 Power Boiler Flue has also been sampled for
 - i) Nitrogen oxides

while the fuel to the boiler was refinery fuel gas.

Particulate matter collected in tests on both the FCCU CO Boiler and the No. 1 Power Boiler has been analyzed for a number of trace metals. By comparing the numbers obtained, inferences are drawn on the origin of elements (oil or catalyst).

- c) The SRU Stack has been sampled for:
 - i) Hydrogen sulphide
 - ii) Sulphur dioxide

The field team responsible for collecting the samples was provided by Arthur Gordon Environmental Evaluators Ltd under subcontract to I.E.C. Beak Ltd.

The analytical services have been provided by the Laboratory Services Branch of the Ontario Ministry of the Environment and I.E.C. Beak Ltd.

The Source Measurement Unit of the Air Resources Branch, Ontario Ministry of the Environment has been the Project Manager, in charge of planning, work co-ordination, results evaluation and report writing.

3. DESCRIPTION OF THE REFINERY

The facilities at Nanticoke process approximately 100,000 barrels per calendar day of light western canadian crude oil.

The major divisions of the refinery are the Process Area, the Loading and Unloading stations, the Water and Waste Water Treatment areas, the Tank Farm and the Administrative Services buildings. In this study the emphasis has been on the emissions from the major fixed sources of the Process Area.

The Nanticoke Refinery includes the following major process units.

CRUDE STILL AND VACUUM UNIT - where crude oil is distilled into various fractions in an atmospheric tower and a vacuum tower.

FLUID CATALYTIC CRACKING UNIT - where heavy distillates from the Crude Unit are cracked catalytically in order to produce high octane gasoline, olefins, middle distillates and fuel gas.

CATALYTIC REFORMING UNIT - where low octane naphta from the Crude Unit is being transformed into high octane products. By-products are fuel gas and butanes.

ALKYLATION UNIT - where olefins obtained in the Fluid Catalytic Cracker are reacted with butanes in the presence of a concentrated solution of sulphuric acid which acts as a catalyst. The products are high octane gasoline, propane and fuel gas.

SULPHUR RECOVERY UNIT - where hydrogen sulphide is removed from the fuel gas and sour water effluent (process water containing sulphur compounds) and converted to elemental sulphur in (three) Claus reactors.

Gaseous effluents generated by all the refinery processes are released to the atmosphere through ten stacks, the majority of which are exhausts of the heaters for different process streams in the refinery. Six of the stacks are contained in a large concrete structure designated as the Multiflue Stack while the remaining four stand as independent sources.

3.1 FLUID CATALYTIC CRACKING UNIT

Catalytic cracking is practised primarily on distilled gas-oil charge stocks. Average yields are forty-five percent gasoline components and forty-five percent catalytic cycle oil. The economical feasibility of the process stems from the fact that it decreases the yield of residual oil produced from crude oil, i.e. the thermal process produces about twice the amount of fuel oil as the amount of coke burned (and residual fuel oil produced) in catalytic cracking. At the same time the octane number of the catalytic gasoline is higher. The large volume of olefinic gases produced in catalytic cracking requires extensive gas recovery and purification systems and necessitates the conversion of these gases into salable products such as polymer gasoline, alkylate gasoline, synthetic rubber, liquified petroleum gases, etc.⁷. At Nanticoke the conversion leads to liquified petroleum gases.

The Nanticoke Plant Fluid Catalytic Cracking Unit (see Figure 1) is of a Texaco design with a rated capacity of 40,000 barrels per day of fresh charge. The FCCU catalytically cracks large, or heavy, components of the crude oil into lighter, smaller components, part of which can be used in the blending of gasoline. A full range of products, from coke to gases to heavy oils, results due to the imprecision of the catalytic reactions.

Preheated feed enters the fresh feed riser, is mixed with hot regenerated catalyst from the Regenerator and travels in a fluidized state up to the Reactor vessel. The cracking of the large feed molecules occurs in the riser, with the disengaging of the products from the catalyst occurring in the Reactor. Recycle oils are similarly handled in the recycle feed riser.

Deposition of by-product coke on the catalyst results in a decline in the catalyst activity. This deactivated catalyst flows from the Reactor through a stripper, where entrained hydrocarbon molecules are removed by steam stripping, and then flows to the Regenerator where its activity is restored by burning off the coke and any included sulphur. The combustion products (flue gas) leave the top of the regenerator and are routed to the CO boiler (located in the Boiler House). Catalyst losses from the Regenerator are minimized by five parallel sets of three-stage internal cyclones.

Reference is made to Figure No. 1 for a schematic of the process equipment.

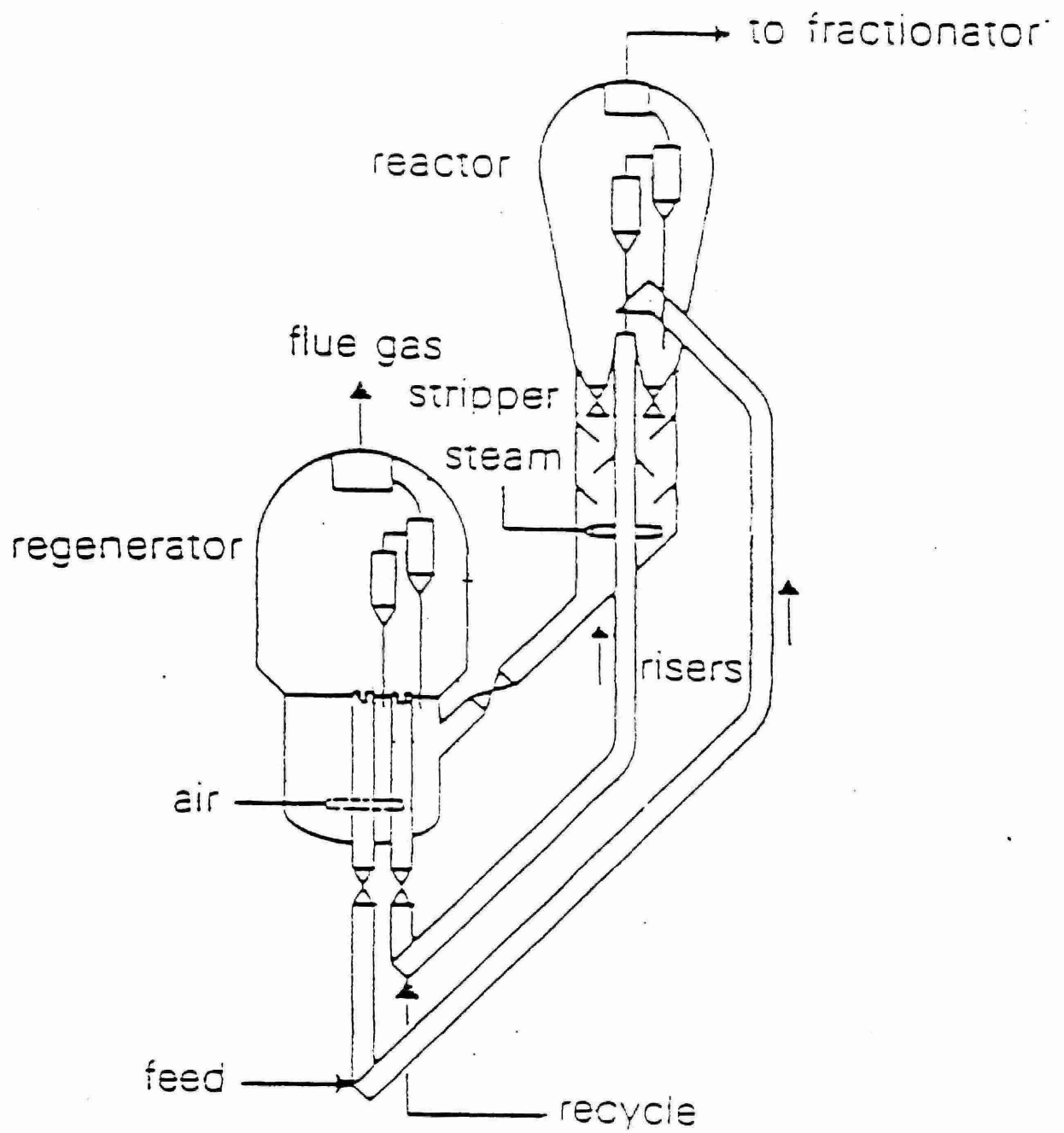


FIGURE No. 1 Fluid Catalytic Cracking Reactor

Gas leaving the cyclones is released to the atmosphere through a one hundred twelve metre high, four metre inside diameter flue, which is part of the "multiflue" stack. A sampling platform is available and four sampling ports (equipped with gate valves) are installed at the ends of two diameters eighty degrees apart at the sixty meter elevation level. The fact that the angle between the two diameters is eighty degrees, rather than ninety, as specified in the provincial source testing code¹ is not considered a major discrepancy.

Because of the minimum length required for sampling along one radius and the physical hindrances at the site, one of the ports (the southern one) was inaccessible for sampling.

The sampling traverses were situated more than eight stack diameters from the nearest upstream disturbance (the flue gas entry) and two stack diameters from the stack exit. The minimum number of sampling points required by the Code¹ was used. For the dimensions of the stack, this meant thirty-two points, sixteen per traverse. Because one of the traverses could be accessed from one end only, and the maximum length of probe which would fit the physical constraints at the site was not long enough to allow sampling over the whole diameter, the following solution was chosen: a probe one metre and a half long was used to sample the traverse which was accessible at both ends; for the other traverse, a probe which was three metres long was slid through the only accessible port and was used to sample at the first twelve points (counting from the inlet port); since the last four points were beyond reach, the sampling was continued at the points situated symmetrically on the traverse, i.e. the first four points were sampled twice. This technique is not expected to have introduced any significant error in sampling; there is no reason to believe that stratification existed in this stack.

3.2 NO. 1 POWER BOILER

The No. 1 Power Boiler, identified as "Spare Power Boiler" in the Ministry records, is, contrary to its name, a "full-time" operating boiler. The design capacity of the unit is 275,000 pounds per hour steam at 900 psig and 750°F. The fuel supplied to the boiler is either oil or refinery gas. The burners are capable of firing fuel gas, fuel oil or any combination thereof. This boiler, one of three

similar ones installed in the refinery, generates a portion of the steam necessary for the plant operations.

Figure No. 2 shows a simplified sketch of the unit.

During the test performed while firing fuel oil, the boiler produced 147,000 pounds per hour steam at 908 psig and 744°F, while during the tests performed when firing refinery fuel gas, the steam production was 140,000 pounds per hour at 920 psig and 753°F.

The exhaust duct is included in the concrete containment structure of the Multiflue Stack where it is designated as Flue No. 4. The inside diameter is 2.6 metres. There are three sampling ports (at the east, west and south end of perpendicular diameters) ten centimeters inside diameter each, provided with gate valves. The sampling platform is at the sixty-two metre level, more than eight diameters downstream of a disturbance (stack entry) and two diameters upstream of another disturbance (stack exit) respectively. This allowed for the minimum number of sampling points to be used -sixteen per traverse - as specified in the Code¹.

3.3 SULPHUR RECOVERY UNIT

Hydrogen sulphide is removed from sour process water by two Sour Water Strippers and from fuel gas by a diethanolamine absorption system. It is subsequently converted to free sulphur in a three stage Claus type reactor. Gas exiting the reactor plus any by-passed feed streams are incinerated to assure the complete conversion of residual hydrogen sulphide to sulphur dioxide.

The incinerator is operating at 1400°F and the flue gases are released to the atmosphere through a ninety metre high, 0.9 m I.D. steel stack. A platform with sampling ports is located at an elevation of about twenty metres. Sampling was performed at a single point, centrally located.

Figure No. 3 provides a flow diagram of the process.

The Sulphur Recovery Unit is designed to recover 95.5 percent of the sulphur charged in the sour water/fuel sweetening off-gases, and its production is rated at thirty-five tonnes of liquid sulphur per day. At the time of the stack testing the

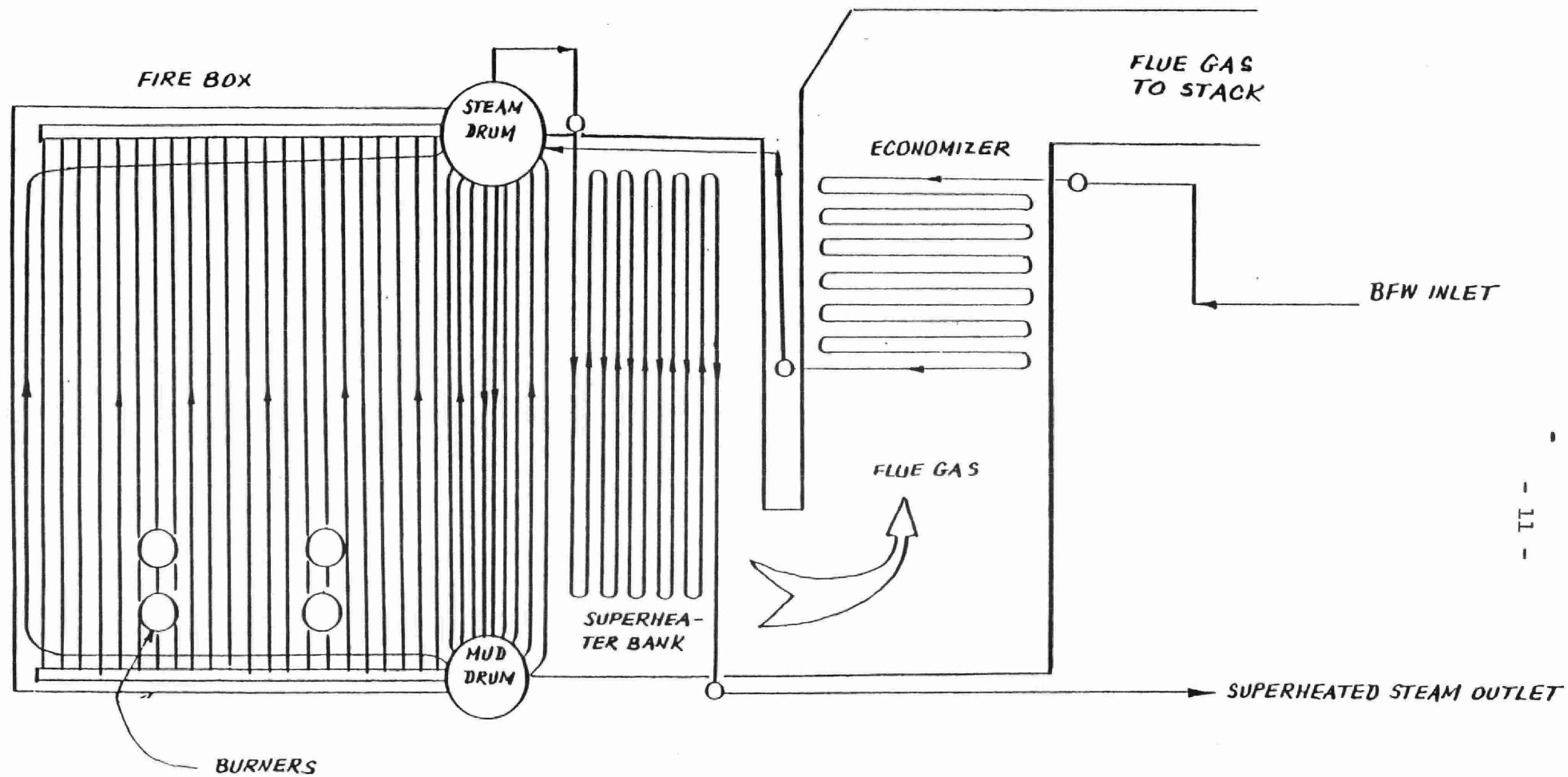


FIGURE No. 2 No. 1 Power Bojler Schematic

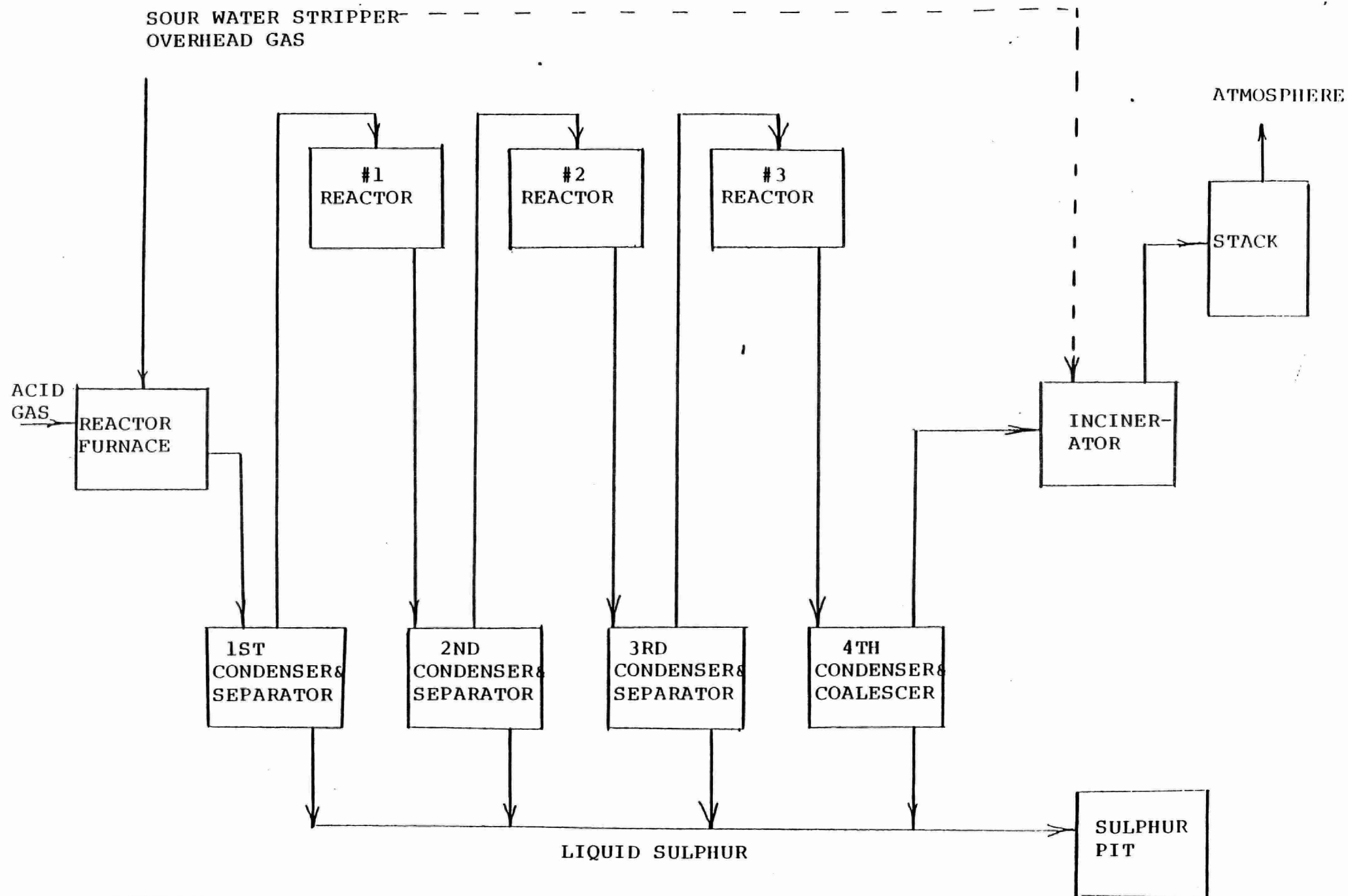


FIGURE No. 3 Process Flow Diagram for Sulphur Recovery (Claus) Unit

estimated production was only thirteen tonnes per day. Either the efficiency of sulphur recovery of the Claus unit was less than design, or a considerable amount of hydrogen sulphide-charged gas was by-passing the desulphurization unit, being sent directly to the incinerator. According to Texaco the second alternative is more likely. Sour water off-gases are routinely sent directly to the incinerator (to avoid the possibility of clogging the Claus beds). In such a case, the real efficiency of the Claus would obviously be higher than the one inferred from the findings of this survey.

Even if all the sulphur output is taken into account (i.e. thirteen tons liquid product plus two tons of sulphur in the exhaust from the incinerator) the overall production of the unit is only forty percent of the rated capacity.

4. SAMPLING AND ANALYSIS

This programme included sampling for particulate matter, sulphur dioxide, nitrogen oxides and hydrogen sulphide. Each contaminant has been sampled and analyzed using techniques recommended by the Ontario Ministry of the Environment.

4.1 PARTICULATE MATTER

Method 5 of the Ontario Source Testing Code¹ has been used for the sampling and analysis of particulate matter .

The portable stack sampler used for testing was specifically designed to determine particulate emissions from stationary sources, as well as to determine the concentrations of various gaseous constituents of interest by chemical absorption. For these tests the equipment was set up to selectively collect particulate matter and water vapour.

The stack sampling equipment was manufactured by Andersen Samplers Inc. under the trade name "Emission Parameter Analyzer". Two identical trains were used for fast sequential access to perpendicular traverses.

The sample was extracted by a probe which consisted of a calibrated nozzle, a heated stainless steel tube and an S-type Pitot tube located adjacent to the nozzle to measure the velocity of the stack gas. A thermocouple was used to determine the temperature in the vicinity of the nozzle.

The probe was directly connected to the "sampling unit" which contained a heated filter and four impingers in series (two filled with water, one empty and one filled with a preweighed amount of silica gel).

An "Umbilical Cord" connected the last impinger to the "Control Unit". Here were all the necessary controls, temperature and pressure instrumentation, the vacuum source and the dry gas meter.

Reference is made to Figure No. 4 for a graphical representation of the complete sampling train.

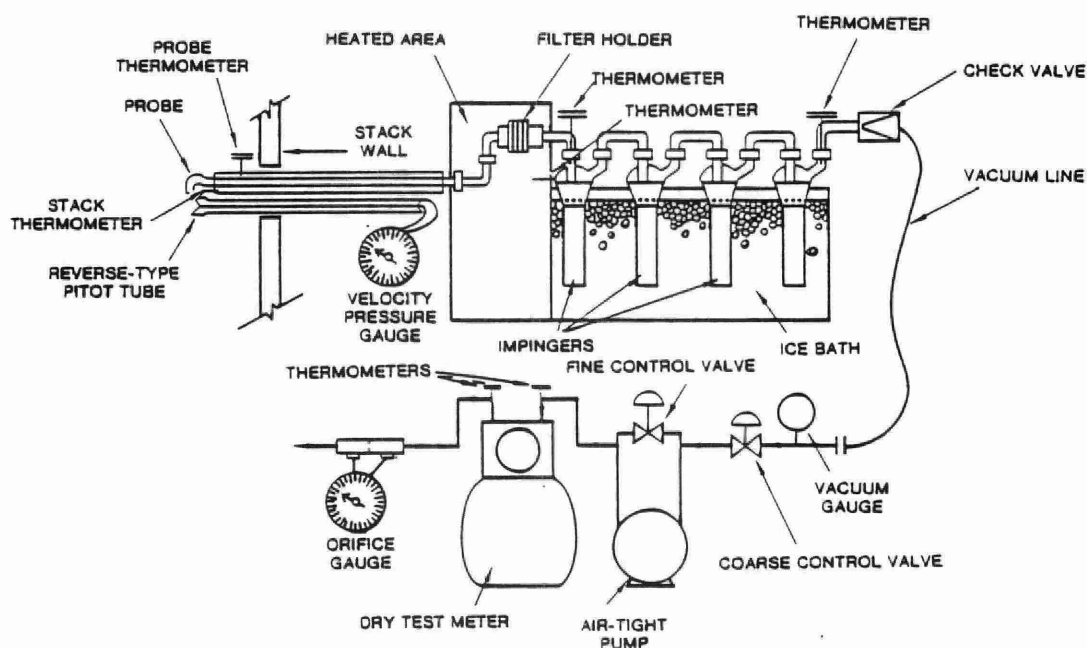


FIGURE No. 4 Sampling Train for Particulate Matter

It is to be noted that the two trains used the same nozzle-probe-sampling unit combination producing a single set of containers (filter, probe wash, impingers) per run.

Each run consisted of drawing a total of a minimum 3.5 m^3 of stack gas from points distributed across the traverses as per the instructions of Method 1 of the Code¹. The sampling time was five minutes per point with readings taken at two and a half minute intervals. A test consisted of three independent runs.

After each run the sampling trains were disassembled in a clean area (in the consultant's van) and the final weights of the impingers were recorded. The filter was carefully removed and placed in a sealed petri dish. The inside of the nozzle, probe and appropriate glassware were washed with acetone and the washings were retained for analysis.

The analysis included weighing of the dessicated filter, the residue remaining after the evaporation of the washing solution and the contents of the impingers. Chemical analysis of both filter and washings was also performed for a number of trace elements.

During each of the three runs at the FCCU CO Boiler Stack a size fractionation of the particulate matter was attempted by separate sampling. The equipment used consisted of an in-stack Andersen impactor, model Mark I, connected directly to the end of a sampling probe and operated via a "Control Unit" identical with the one described above. A metallic condenser was used in front of the control unit. The impactor was made of stainless steel and had eight impaction plates and a fibre-glass back-up filter. Sampling was performed isokinetically at a single, central point, for half an hour each run. After each run, the impactor was disassembled in a clean area and the dry dessicated plates were weighed. The deposits on the plates and the back-up filter were analyzed for trace elements.

4.2 SULPHUR DIOXIDE

The method used for sampling and analysis of sulphur dioxide was based on the one explained in the 1973 version of the Ontario Source Testing Code⁵, and slightly modified for the purpose of this test. The changes involved the use of standard impingers instead of the midget ones; the volume of reagents used and the

sampling rate were increased accordingly (by a factor of ten). The content of the first impinger of the train has not been discarded but rather kept separately from the rest and analyzed in an attempt to ascertain the sulphur trioxide content of the stack gases. The analytical method differed from the one in the reference method. Instead of barium perchlorate titration, the Laboratory Services Branch had the solutions analyzed for sulphate ion by ion chromatography, for faster and more accurate results.

The gas was extracted from a single point near the centre of the stack with a sampling train almost identical with the one used for particulate matter. The only differences were in the absence of the filter and the button hook nozzle at the end of the probe. For these tests the probe was lined with a Pyrex glass tubing. The tube was packed with glass wool at the end connected to the first impinger. The "Sampling Unit" contained four impingers filled with isopropanol (the first), hydrogen peroxide (the following two), and silica gel (the last one). The "Control Unit" was identical to the one used in the tests for particulate matter.

A test consisted of three separate runs. The Fluid Catalytic Cracking and the No. 1 Power Boiler runs lasted about half an hour each while the runs at the Sulphur Recovery Unit stack were only about half as long.

Attention is drawn on the fact that the results reported as "sulphate" do not include the amounts which might have been recovered by analysis of the probe and glass wool plug washings and could also have been affected by sampling at a fixed rate (rather than isokinetically) and at a single point.

4.3 NITROGEN OXIDES

The sampling and analysis methods for nitrogen oxides were as described in the 1973 version of the Ontario Stack Sampling Code⁵.

Evacuated flasks have been used to obtain grab samples of gas from a point near the centre of the stack. The absorbing solution was a solution of hydrogen peroxide in sulphuric acid as required by the method, but the analysis for nitrate was performed by ion chromatography, which gives results at least as accurate as the spectrophotometrical determination required by the reference method.

A test for nitrogen oxides consisted of nine separate samples. They were taken concomitantly with the samples for particulate matter by filling three bottles of gas at equal intervals during each run for particulate matter.

Reference is made to Figure No. 5 for the exact configuration of the sampling train for nitrogen oxides.

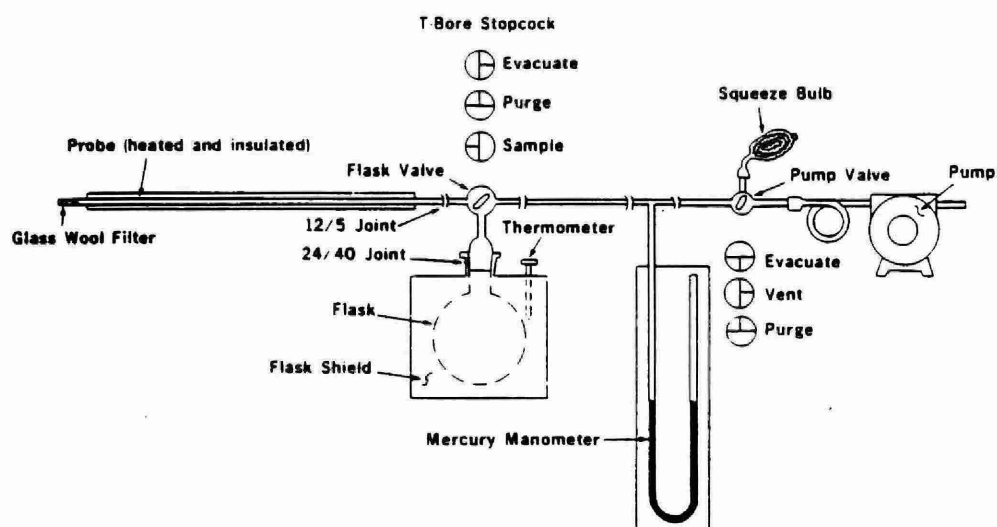


FIGURE No. 5 Sampling Train for Nitrogen Oxides

4.4 HYDROGEN SULPHIDE

The method for sampling and analysis of hydrogen sulphide at the stack of the Sulphur Recovery Unit was based on Method 11 published by the Environmental Protection Agency of the United States⁶, with the following modifications

- Regular size impingers were used rather than the midget type recommended by the reference method and the volume of absorbing solution and the sampling flow rate were increased accordingly (by a factor of ten).
- To scrub effectively the relatively large amount of sulphur dioxide present in the gas, two impingers (in series) filled with hydrogen peroxide were used, rather than one as recommended by the reference method.

- A glass wool plug was inserted at the end of the probe connected to the impingers rather than at the end inserted in the stack. This was done because the high temperature in the stack melted a plug inserted at the tip of the probe during a preliminary run, thus plugging the probe.

The gas was extracted from a point more than eight stack diameters downstream and more than two diameters upstream from disturbances and near the centre of the cross-sectional area. The sampling lasted for about twelve minutes per run. Three runs were performed.

The sampling train consisted of the same general three sections as the one used for particulate matter and sulphur dioxide, but with some modifications.

The probe was made out of quartz glass and it was unsheathed. There was no Pitot tube attached to the probe; the flow was controlled by reading the dry gas meter volumes and keeping constant the pressure drop at the orifice in the Control Unit.

The "Sampling Unit" had seven impingers in series. The first two contained 150 ml of three percent hydrogen peroxide each. They were followed by an empty one and then three impingers filled with 100 ml cadmium sulphate solution. The last impinger was filled with a preweighed amount of silica gel.

The "Control Unit" was similar to the ones used in the particulate matter sampling train.

The recovery and analysis were conducted exactly as described in the reference method. All the samples were analyzed for hydrogen sulphide within one hour of their collection.

The content of the first two impingers were sent to the Laboratory Services Branch for sulphate analysis by ion chromatography.

5. DISCUSSION OF RESULTS

5.1 FLUID CATALYTIC CRACKING UNIT CO BOILER

The stack of the Fluid Catalytic Cracking Unit CO Boiler was analyzed for total particulate matter, sulphur dioxide and nitrogen oxides. A slight modification of the sampling method for sulphur dioxide allowed the obtainment of an estimate of the sulphate levels.

Separate particle sizing tests were performed in order to establish the particle size distribution of the solids emitted into the atmosphere. Run No. 1 of the tests for all the contaminants, as well as Run No. 1 of particle size testing, occurred on November 16, while Runs Nos. 2 and 3 were carried out on November 17.

A complete summary of the tests performed at this stack is provided in Table No. 13.

5.1.1 Total Particulate Matter

The emission rate of total particulate matter from the FCCU CO Boiler Stack was found to be about 11 g/s. This corresponds to an emission factor of 162 grams of solids per cubic meter of feed to the cracking reactor. The concentration of solids in the exhaust gas was found to be 217 mg/m³. All the results have coefficients of variation smaller than twenty percent. The concentrations found in this study fall within the range of values quoted in the literature, i.e. 27 mg/m³ to 700 mg/m³ for such sources⁸. Table No. 3 summarizes the results of the tests.

A general remark should be made about the production parameters during the period of the tests. According to the Company (i.e. Texaco) most production parameters were at their normal values. The exception was the "throughput ratio" which is defined as the ratio of the sum of fresh and recycle feeds to the fresh feed. This ratio was close to one, i.e. no recycle, while normally it should be around 1.25. This condition was caused by an abundance of fresh feed which had to be consumed fast. It could be surmised that such an operation produced somewhat lower emissions than would have been observed under normal operating conditions. This is because the recycle feed, being a heavier fraction, would be enriched in metallic and non-metallic contaminants and the normal mixture would thus be "dirtier" than the fresh feed alone.

5.1.2 Particle Size Distribution

The particle sizing experiments have produced results showing that over eighty percent of the particulate matter emitted into the atmosphere is in the "respirable range", i.e. with an aerodynamic diameter of less than ten microns. About forty percent of the emissions are submicronic. The mean aerodynamic diameter is in the range 2.2-2.4 microns (Figures 6-8). The validity of the sizing experiments is supported by the good replication of the three tests (Tables 5-7) and by the general agreement of concentration results obtained in particle sizing tests with the results of the total particulate matter samples (Tables 3 and 4). A small but consistent difference between the concentration observed in total particulate matter tests and particle sizing tests is considered to be a negative bias of the latter. This could have been caused by the fact that particle sizing was conducted in a shorter time and at a single point in the stack. The multitude of parts of an Andersen impactor and the cleaning technique (brushing), which is less vigorous and complete than the one used with the particulate matter sampling train, could also produce less than perfect recovery of the solids from the collection media. Finally, the fact that weighing of the fraction collected in the two different tests was made by different analysts in different laboratories (i.e. Arthur Gordon did all the weighing required in the particle sizing tests while weighing for all the other tests has been the responsibility of the Laboratory Services Branch of MOE) could also have introduced a small systematic error.

5.1.3 Trace Element Analysis

Trace elements analysis was performed on all the fractions recovered from the sampling train for total particulate matter (i.e. probe and nozzle, washings, filter and impingers) as well as on all the stages of the Andersen impactor. For a justification of these analysis refer to paragraph 5.2.1.

The results obtained from the particulate matter tests are summarized in Table No. 8. Some factors other than the FCCU feed or catalyst compositions might have affected the results. Iron, chromium and nickel could have originated from the boiler tubes. Another source for these elements could have been the components of the chromium-nickel stainless steel Regenerator itself.

The repartition of the elements between the different fractions collected allows several conclusions to be drawn.

Arsenic, for example, is probably present in the stack gas as either a compound which is in vapour phase at that temperature (211°C) but which solidifies above the temperature of the filter housing (105°C), or it is associated with the finer aerosol. This is inferred from its presence on the filter and its absence in the other fractions (Table 8), and from the fact that the concentration of arsenic found in the in-stack Andersen sampling is lower than that of the regular sampling for particulate matter (Table 16).

Lead is somewhat similar in its comportment and so is vanadium.

Zinc and chromium appear to be associated mainly with medium size particulate matter, i.e. about three-four microns. (Tables 8 and 9)

Manganese, copper, nickel, and iron are evenly distributed in all the sizes collected (Tables 9 and 10). This is also confirmed by the fact that their distribution in the washings and filter fractions in the particulate matter sampling train closely follow the distribution of all the solids collected (Table 8).

Strontium and barium show up mostly in the filter portions in both the particulate matter and in the particle sizing tests. This would tend to indicate that these elements are associated with the finer solid aerosol present in the stack gas.

Cadmium and cobalt are present in minute amounts in all the size fractions collected.

As a general observation, the finest fraction collected, the one on the back-up filter of the Andersen impactor, is always very rich in metals compared with the rest (Table 10). This might suggest that very fine metallic fumes are formed separately and/or in addition to the other dust particles, to which they may subsequently become attached by some mechanism(s).

There is a further discussion of the results of trace elements analysis in paragraph 5.2.1.

5.1.4 Sulphur Dioxide

The sampling method for sulphur dioxide was modified slightly to allow for a measurement of sulphate levels to be obtained. "Sulphate" is defined here as the fraction collected in the first impinger (containing isopropanol) and it is probably representative of the levels of sulphur trioxide in the flue gas.

The sulphate contribution to the total sulphur emissions of the stack was found to be low, i.e. less than half a percentage point, all the rest being sulphur dioxide (Table 11).

Sulphate emissions to the atmosphere from the FCCU CO Boiler Stack were found to be about 1.4 g/s. This corresponds to a concentration of 28.1 mg/m³ which is within the range found in other published data (2.6 to 54 mg SO₄²⁻/m³ in reference 8).

Sulphur dioxide levels are much higher - emission rate is 237.8 g/s and concentration is 4.87 g/m³ - but again within the range of other literature references (up to 7.2 g/m³ in reference 9).

The results of the tests are summarized in Table 11.

No explanation can be advanced for the variability encountered in the tests for sulphur dioxide. Existing production records (see Appendix 1) do not reveal any significant event which could have affected the results of the first test but it should be borne in mind that the production records average their values over a much longer period of time than the stack sampling runs. A continuous graphical record of the fresh feed rate and the catalyst circulation rate, which might have shed some light on the reason for obtaining such different results, was unavailable.

5.1.5 Nitrogen Oxides

The Fluid Catalytic Cracking Unit utilizes a new type of zeolite catalyst which promotes the cracking in the riser rather than in the fluidized bed of the reactor itself. The advantage of riser cracking over bed cracking lies in avoiding secondary reactions such as the re cracking of gasoline

components. This catalyst, though, is more sensitive to coking than older, more conventional types (of catalyst). The way to maintain a low carbon-on-catalyst level (typical values are in the range of 0.05 - 0.1 percent coke on the catalyst range) is a technique called High Temperature Regeneration (HTR). The key to this process is the complete conversion of the CO, generated in the process of burning the coke, into CO₂ within the regenerator (as opposed to only 50% conversion of CO to CO₂ in conventional regenerator). High temperature and an increased concentration of oxygen available in the gas are responsible for the appearance of some "thermal NO_x". Residual CO and some additional refinery fuel gas is burnt in the CO Boiler and the energy is recovered as steam. Some more NO_x is created in the process. In an attempt to quantify the emissions attributable to the FCCU alone from the results obtained at the stack of the CO Boiler, an additional source of similar characteristics (the No. 1 Power Boiler burning refinery fuel gas) was sampled and the calculated emission factor for gas burning was subtracted from the results observed at the CO Boiler. For a discussion of the limitations associated with this calculation refer to section 2.

The average emission rate of NO_x (expressed as NO₂) at the stack of the CO Boiler was 11.08 g/s with a corresponding concentration of nitrogen oxides in the flue gas of 224.5 mg/m³. This yields an emission factor of 168.4 g NO_x per cubic meter of fresh FCCU feed or, corrected for the contribution of the additional fuel as explained above, 157.3 g NO_x per cubic meter of fresh FCCU feed. Results are summarized in Table 12.

The minor contribution of the fuel gas combustion as compared with catalyst regeneration in the total emission of nitrogen oxides is not unexpected if one considers the kinetics of NO formation. The rate of formation of the product is so much slower than the combustion itself, that the formation of NO occurs after the combustion process and is purely thermal in nature. The rate of NO formation thus depends on the heat of combustion of the fuel and not on its chemical nature. Preheating the fuel mixture is equivalent to increasing its heat of combustion¹⁰. In the case of the FCCU CO Boiler, the HTR process which precedes the boiler provides the optimum conditions for a high conversion to NO. Overall, the effect is comparable to a gas burning process (Table 22) although the major part of the heat release is done in the absence of an open flame.

5.2 NO. 1 POWER BOILER

The stack of the No. 1 Power Boiler has been sampled and analyzed for total particulate matter, sulphur dioxide and nitrogen oxides. Tests for nitrogen oxides have been performed in two situations:

1. when the fuel in use was No. 6 Fuel Oil and
2. when the burner was fired on purified refinery fuel gas.

Tests for particulate matter and sulphur dioxide were carried out while the fuel to the boiler was No. 6 Fuel Oil only. Particulate matter collected in all the fractions of the sampling train was analyzed for trace metals (same list of elements as for the CO Boiler). A complete summary of the tests performed at this stack is provided in Table No. 21.

5.2.1 Total Particulate Matter and Trace Metal Analysis

Tests for total particulate matter were performed following the Reference Method¹.

The emission rate was found to be 1.05 g/s corresponding to a concentration of solids in the flue gas of 45.9 mg/m³. This yields an emission factor of about 679 g per tonne of fuel oil burned. Table 14 summarizes the results of the tests.

The analysis of trace elements in the total particulate matter emitted by the No. 1 Power Boiler stack has been performed for two reasons:

- firstly, it has been considered that the No. 1 Boiler is a source which is representative of all the other boilers or heaters using the same fuel. Knowing the concentration of different elements in the solids emitted by this stack allows one to work out emission factors and element budgets by source or for the whole refinery;
- secondly, it was hoped that a comparison between the concentration of trace elements in the feed, FCCU catalyst and particulate matter emitted from the stack, will allow a material balance to be closed around the FCCU for all the trace elements under study.

The Company (i.e. Texaco) did not make available samples of used catalyst and fresh feed. Thus, the material balance could not be calculated with the results of the stack testing alone.

The results of trace metals analysis in the No. 1 Power Boiler emissions are summarized in Table No. 15.

Several general comments on the results could be made.

Arsenic is present mainly in the filter catch. This could be either because it is associated with the finer particles or because it is in gaseous form at the stack temperature (185°C) but condenses at the temperature of the filter (105°C).

Lead and vanadium mimic the arsenic.

Zinc, on the other hand, seems to be a component of the large size particles (larger than about five microns).

Strontium and barium appear on the filter only, hence the inference that they are associated with smaller aerosols.

Nickel and iron exceed in concentration all the other elements combined and appear to be evenly distributed in the probe and filter catches suggesting that they are evenly distributed in particles of all sizes.

All the other elements assayed were present in minute amounts.

Table 16 presents a comparison of trace elements concentration in the Alberta Oil, in the catalyst used by the FCCU and in the emissions of the CO Boiler and No. 1 Power Boiler.

5.2.2 Sulphur Dioxide

The sampling method for sulphur dioxide was slightly modified to allow for separate determination of the sulphate levels. Attention is drawn to the fact that the accuracy of the sulphate levels is not expected to be as high as that of sulphur dioxide.

The emission rate of sulphate was found to be 1.53 g/s and that of sulphur dioxide 57.74 g/s corresponding to a concentration in the flue gas of 73.4 mg/m³ and 2660.1 mg/m³ respectively. This translates into emission factors of 1.04 kg sulphate per tonne of fuel burned and 39.40 kg sulphur dioxide per tonne of fuel burned. These results are summarized in Table 17.

5.2.3 Nitrogen Oxides

The No. 1 Power Boiler was sampled for nitrogen oxides while run on both No. 6 Fuel Oil and refinery fuel gas. The results are presented in Tables 18 and 19 respectively.

For the gas fired period, the emission rate was found to be 6.94 g per second expressed as nitrogen dioxide. This corresponds to a concentration of 303.5 mg NO₂/m³ or an emission factor of 5.16 g NO₂ per thousand cubic meters of gas. These numbers were used in conjunction with the results obtained in the tests on the FCCU CO Boiler to find the emission rate of the FCCU alone by subtracting the nitrogen oxides generated in the burning process in the CO boiler.

For the oil fired period, the emission rate was more than double, at 15.58 g NO₂ per second which corresponds to a concentration of 715.4 mg NO₂/m³ or an emission factor of 10.65 g NO₂ per tonne of fuel oil.

A meaningful comparison of the emissions is found in Table 21 which presents the emission rates per megajoule of useful heat produced in the boiler. It was to be expected that the slower burning of a liquid fuel creates more nitrogen oxides than the much faster burning of a gas fuel. The tests have shown that, in this case, No. 6 Fuel Oil generates more than double the amount of NO_x for the same boiler load than the refinery gas fuel.

5.3 SULPHUR RECOVERY UNIT

The stack of the Sulphur Recovery Unit has been sampled for sulphur dioxide and hydrogen sulphide. The sulphur dioxide sampling method has been modified to allow for the concomitant determination of the sulphur present in the gas as sulphate ion (as sulphur trioxide or sulphuric acid).

Emission rates for sulphate, sulphur dioxide and hydrogen sulphide were found to be 1.62, 51.9 and 0.00242 g/s respectively. This corresponds to concentrations of 917, 30176 and 1.427 mg/m³ for sulphate, sulphur dioxide and hydrogen sulphide respectively.

Results of these tests are summarized in Tables 22 and 23.

Comparisons between all the tests for sulphate/sulphur dioxide furnish some interesting conclusions.

For example, the degree of sulphur oxidation to sulphate is greatest in the stack of the Sulphur Recovery Unit where strong oxidizing conditions should prevail most of the time. Two percent of the sulphur is present in this source as sulphate ion compared with only 1.7% and 0.4% in the stacks of the No. 1 Power Boiler and CO Boiler respectively. (This follows the ranking of the sources in terms of sulphur concentration strength.)

Sulphur emissions from the Sulphur Recovery Unit are about two tonnes per day. The sulphur production of the Unit during testing, as estimated by Texaco personnel, was thirteen tonnes per day. When judging these numbers, due weight should be given to the fact that the stack sampling lasted for only three fifteen minute periods in a total time lapse of two hundred minutes while Texaco's estimate was for the whole day. Nevertheless, since the company attempted to maintain "fairly constant and representative conditions" during the sampling period, the conversion of their Claus unit appears to be low. In this context, the thirteen tonnes of sulphur per day production of a unit rated at thirty-five tonnes per day is low and the measured emissions are representative of only this production level. An explanation of the possible cause for the apparently low conversion rate - the by-passing of the Claus by some of the sour gas streams (see Section 3.3) - is not influencing the conclusion that, at testing time production rate was much lower than the quoted "Name Plate" capacity - thirty-five tonnes per day.

6. CONCLUSIONS AND RECOMMENDATIONS

Three major stacks at the Nanticoke refinery of Texaco Canada Inc. have been tested for their most significant contaminants.

The results obtained for the FCCU CO Boiler stack (Table 13) are within the range quoted by literature sources. The coefficient of variation for the emission rate of particulate matter and sulphate is 11.9 and 17.9 percent respectively. Larger coefficients of variation are obtained for the emission rates of sulphur dioxide and nitrogen oxides - 63.3 and 54.3 percent respectively. The cause for these larger variations are much smaller concentrations observed in the first SO₂ run and the last NO_x run than in the other two runs (which are in turn fairly close together). As a result of these stack tests, the pollutant emission rates for particulate matter, sulphur dioxide and nitrogen oxides can be revised upward by twenty-five and forty-six percent and downward by twenty-two percent respectively (Tables 1 and 2).

If more accurate numbers are needed for sulphur dioxide and nitrogen oxides, it is recommended that the source be sampled again with continuous monitors while a close tab is being kept on all the process variables (FCCU feed flowrate and composition, catalyst flowrate and composition, etc.).

The results obtained at the No. 1 Power Boiler Stack (Table 20) are within the range reported in the literature. The coefficient of variation for the emission rate of particulate matter, sulphate, sulphur dioxide and nitrogen oxides while burning No. 6 fuel oil was 4.6, 90.0, 9.1 and 22.9 (percent) respectively. The coefficient of variation for the emission rate of nitrogen oxides while burning refinery fuel gas was 37.5 (percent). The first run produced a much larger result for sulphate than the subsequent two runs while in the case of nitrogen oxides the third run produced comparatively larger results which are responsible for the scatter.

The results of these tests are considered accurate for the purpose for which they were intended. Emission factors per megajoule of generated heat (Table 21) are convenient for calculating the total emissions of the refinery, provided that the untested heat sources are reasonably similar to the tested ones.

The tests conducted at the stack of the Sulphur Recovery Unit have produced results which suggest that the emission rate of sulphur dioxide should be revised upward by one hundred and thirty percent from the previously available value (22.6 g/s per submission for the Certificate of Approval). The coefficient of variation of the results obtained in the three runs is 23 (percent). The hydrogen sulphide tests have also produced results with relatively little scatter (coefficient of variation is 31.6 percent).

The significance of these tests is somewhat limited by the fact that the production rate of the Claus unit was much less than the design figure. The efficiency of the Claus installation is apparently low but this could have been caused by sulphur rich streams by-passing the Claus and being sent directly to the incinerator.

For a clarification of the doubtful points raised above, it is recommended that this source be retested under maximum operating rates.

BIBLIOGRAPHY

1. "Source Testing Code (Version #2)", Report #ARB-TDA-66-80, November 1980, Ontario Ministry of the Environment.
2. "A Preliminary Study of the Emissions of Hydrocarbons from the Texaco Refinery Tank Farm", Report ARB-013-81-ETRD, May 1981, Ontario Ministry of the Environment.
3. "Hydrocarbon Emissions from the Texaco Refinery Tank Farm", Report ARB-024-81-ETRD, Ontario Ministry of the Environment.
4. "Ambient Hydrocarbons Survey in the Nanticoke Area", Report ARB-TDA-65-80, September 1980, Ontario Ministry of the Environment.
5. "Source Testing Code, January 1973", Ontario Ministry of the Environment.
6. Code of Federal Regulations, Title 40, Part 60, Paragraph 60.344, Appendix A, July 1, 1980, U.S.G.P.O.
7. "Petroleum Refinery Engineering", W. L. Nelson, 4th Ed. McGraw-Hill Book Co.
8. "Assessment of Atmospheric Emissions from Petroleum Refinery", July 1, 1980, Radian Corporation.
9. "Screening Study to Determine Need for SO_x and Hydrocarbon NSPS for FCC Regenerators", Report EPA-450/3-77-046, August 1976, Arthur D. Little Inc.
10. "Flue Gas Monitoring Techiques", J. N. Driscoll, 1974, Ann Arbor Science Publishers Inc.

TABLE I

SUMMARY OF TEST RESULTS OBTAINED AT THREE MAJOR STACKS IN THE NANTICOKE REFINERY OF TEXACO

STACK	Particulate Matter		Sulphur Dioxide		Nitrogen Oxides (as NO ₂)		Hydrogen Sulphide	
	Concentration (mg/DSCM)	Emission Rate (g/s)	Concentration (mg/DSCM)	Emission Rate (g/s)	Concentration (mg/DSCM)	Emission Rate (g/s)	Concentration (mg/DSCM)	Emission Rate (mg/s)
FCCU CO Boiler	216.8 ⁺ 22.5 ⁻	10.67 ⁺ 1.27 ⁻	4870.2 ⁺ 311.7 ⁻	237.82 ⁺ 150.43 ⁻	224.5 ⁺ 121.6 ⁻	11.1 ⁺ 6.0 ⁻	-	-
No. 1 Power Boiler (Buring No. 6 Fuel Oil)	45.92 ⁺ 1.69 ⁻	0.995 ⁺ 0.046 ⁻	2660.1 ⁺ 86.8 ⁻	57.74 ⁺ 5.24 ⁻	715.4 ⁺ 142.6 ⁻	15.58 ⁺ 3.58 ⁻	-	-
No. 1 Power Boiler (Burning Refinery Fuel Gas)	-	-	-	-	303.5 ⁺ 113.7 ⁻	6.94 ⁺ 2.60 ⁻	-	-
Sulphur Recovery Unit	-	-	30176 ⁺ 7216 ⁻	51.93 ⁺ 11.97 ⁻	-	-	1.427 ⁺ 0.451 ⁻	2.42 ⁺ 0.77 ⁻

NOTE: The range of all the results is quoted as the average plus or minus one standard deviation.

TABLE 2

ESTIMATED EMISSIONS FROM MAJOR EXHAUST STACKS
AT THE TEXACO REFINERY IN NANTICOKE*

NO.	STACK	DIMENSIONS(m)	GAS EXIT CONDITIONS		POLLUTANT EMISSIONS (g/s)		
			TEMP.(°C)	VELOCITY(m/s)	PARTICULES	SO ₂	NO _x
1.1	Crude Charge Heater Vacuum Charge Heater Naphta Splitter Reboiler Htr.	112H x 3.5 i.D.	?	?	5.17	46.76	18.36
1.2	FCCU Charge Heater	112H x 1.9 i.D.	?	?	1.11	10.10	3.91
1.3	CO Boiler	112H x 4.1 i.D.	232	5.8	8.57	162.44	14.24
1.4	No. 1 Power Boiler	112H x 2.6 i.D.	177	4.3	-	-	-
1.5	Power Boiler	112H x 3.0 i.D.	?	?	5.20	48.38	20.16
1.6	CO Boiler By-Pass	112H x 2.5 i.D.	677	16.2	-	-	-
1	Multiflue	112H x 11.6 I.D.	232	18.3	20.05	267.63	56.65
2	Unifiner Charge Heater	54H x 1.4 I.D.	343	2.6	0.06	0.00	0.35
3	Combined Stack	56H x 2.1 I.D.	310	4.4	0.38	0.01	1.57
4	Platformer Charge Heater	104H x 3.3 I.D.	204	4.3	1.08	0.03	6.30
5	Sulphur Recovery Unit	91H x 0.9 I.D.	704	7.6	-	22.60	0.24

* Source of Estimates: Environmental Approvals and Project Engineering Branch of M.O.E.

TABLE 3
SUMMARY OF THE PARTICULATE MATTER TESTS AT THE STACK
OF THE CO BOILER

RUN No.	Sampling Time (min)	Stack Temp. (°C)	Relative Humidity (%)	Production Rate (Fresh FCCU Feed Rate) (m ³ /h)	Volume of Gas Sampled (DSCM)	Stack Gas* Velocity (m/s)	Stack Gas Flowrate (DSCMS)	Particulate Matter Concentration (mg/DSCM)
1	160	205	13.16	237.2	3.472	7.2	49.99	242.7
2	160	211	12.51	236.3	3.410	7.1	49.12	202.3
3	160	218	13.29	237.7	3.388	7.1	48.35	205.3
Average	160	211 ⁺ ₇	12.99 ⁺ _{0.42}	237.1 ⁺ _{0.7}	3.423 ⁺ _{0.044}	7.1 ⁺ _{0.1}	49.15 ⁺ _{0.82}	216.8 ⁺ _{22.5}
Coefficient of Variation $C_v = 100 \cdot \frac{\bar{S}}{\bar{X}}$	0	3.1	3.2	0.3	1.3	0.7	1.7	10.4

* Actual conditions

TABLE 4
SUMMARY OF THE RESULTS OF THE PARTICULATE SIZING TESTS
AT THE STACK OF THE CO BOILER

Run No.	Sampling Time (min)	Stack Temperature (°C)	Relative Humidity (%)	Volume of Gas Sampled (DSCM)	Stack Gas Velocity* (m/s)	Stack Gas Flow Rate (DSCMS)	Particulate Concentration (mg/DSCM)	Emission Rate (g/s)	Average Isokinetics %I	Emission Rate (g/s)	Emission Factor (g/m ³ fuel)	Average Isokinetics %I
1	30	216	10.3	28.91	7.5	52.75	155.1	8.19	91.1	12.14	184.25	98.62
2	30	218	13.0	28.55	7.1	47.98	192.6	9.25	92.9	9.94	151.43	98.40
3	30	220	13.8	28.47	7.4	49.43	168.38	8.33	92.6	9.93	150.39	99.46
Average	30	218 ⁺ ₂	12.4 ⁺ _{1.8}	28.64 ⁺ _{0.23}	7.4 ⁺ _{0.2}	50.05 ⁺ _{2.45}	172.03 ⁺ _{19.01}	8.59 ⁺ _{0.58}	92.2 ⁺ _{1.0}	10.67 ⁺ _{1.27}	162.03 ⁺ _{19.25}	98.83 ⁺ _{0.56}
Coefficient of Variation $C_v = 100 \cdot \frac{\sum}{\bar{X}}$	0	1.0	14.8	0.8	3.0	4.9	11.1	6.7	1.0	11.9	11.9	0.6

* Actual conditions

TABLE 5
PARTICLE SIZE DISTRIBUTION OF PARTICULATE MATTER EMITTED
BY THE STACK OF THE CO BOILER - TEST NO. 1

Stage	Weight Collected (mg)	% in Size Range (%)	Cumulative % Less Than Size Range (%)	Size Range (um)	Effective Cut Diameter (um)
0	10.0	13.57	86.43	11.00	11.00
1	11.7	15.88	70.56	6.80 - 11.00	6.80
2	3.8	5.16	65.40	4.60 - 6.82	4.60
3	5.3	7.19	58.21	3.15 - 4.60	3.15
4	7.4	10.04	48.17	2.00 - 3.15	2.00
5	8.8	11.94	36.23	0.97 - 2.00	0.97
6	16.1	21.85	14.38	0.62 - 0.97	0.62
7	9.6	13.03	1.36	0.42 - 0.62	0.42
Filter	1.0	1.36	0.00	0.30 - 0.42	0.30
Total	73.7				

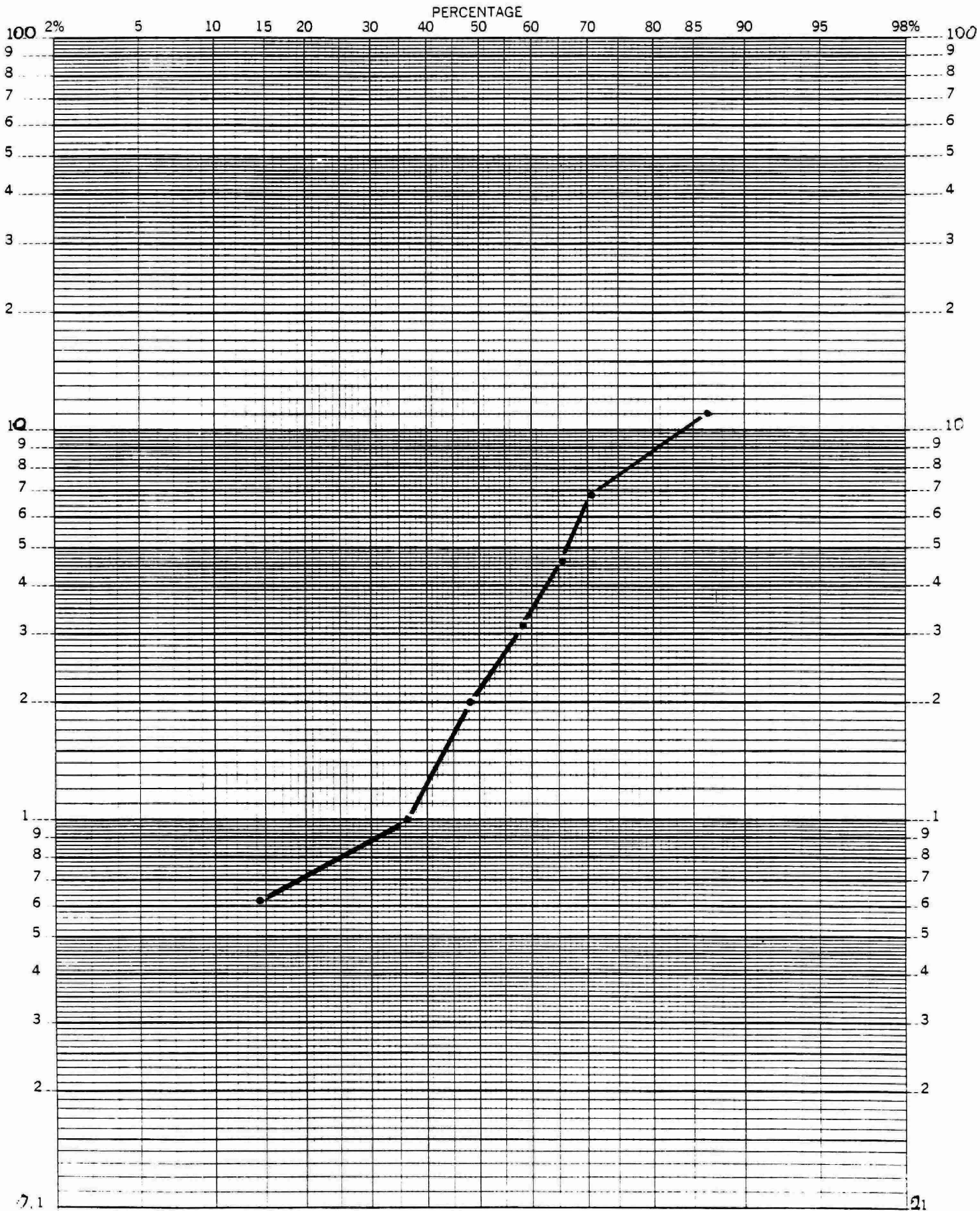


FIGURE No. 6 Particle Size Distribution of Particulate Matter
Emitted by the Stack of the CO Boiler - Test 1

TABLE 6
PARTICLE SIZE DISTRIBUTION OF PARTICULATE MATTER EMITTED
BY THE STACK OF THE CO BOILER - TEST NO. 2

Stage	Weight Collected (mg)	% in Size Range (%)	Cumulative % Less Than Size Range (%)	Size Range (um)	Effective Cut Diameter (um)
0	11.6	13.65	86.35	11.50	11.50
1	9.8	11.53	74.82	7.20 - 11.50	7.20
2	8.1	9.53	65.29	4.80 - 7.20	4.80
3	7.3	8.59	56.71	3.30 - 4.80	3.30
4	8.6	10.12	46.59	2.15 - 3.30	2.15
5	10.3	12.12	34.47	1.05 - 2.15	1.05
6	16.2	19.06	15.41	0.65 - 1.05	0.65
7	10.4	12.24	3.18	0.44 - 0.65	0.44
Filter	2.7	3.18	0.00	0.30 - 0.44	0.30
Total	85.0				

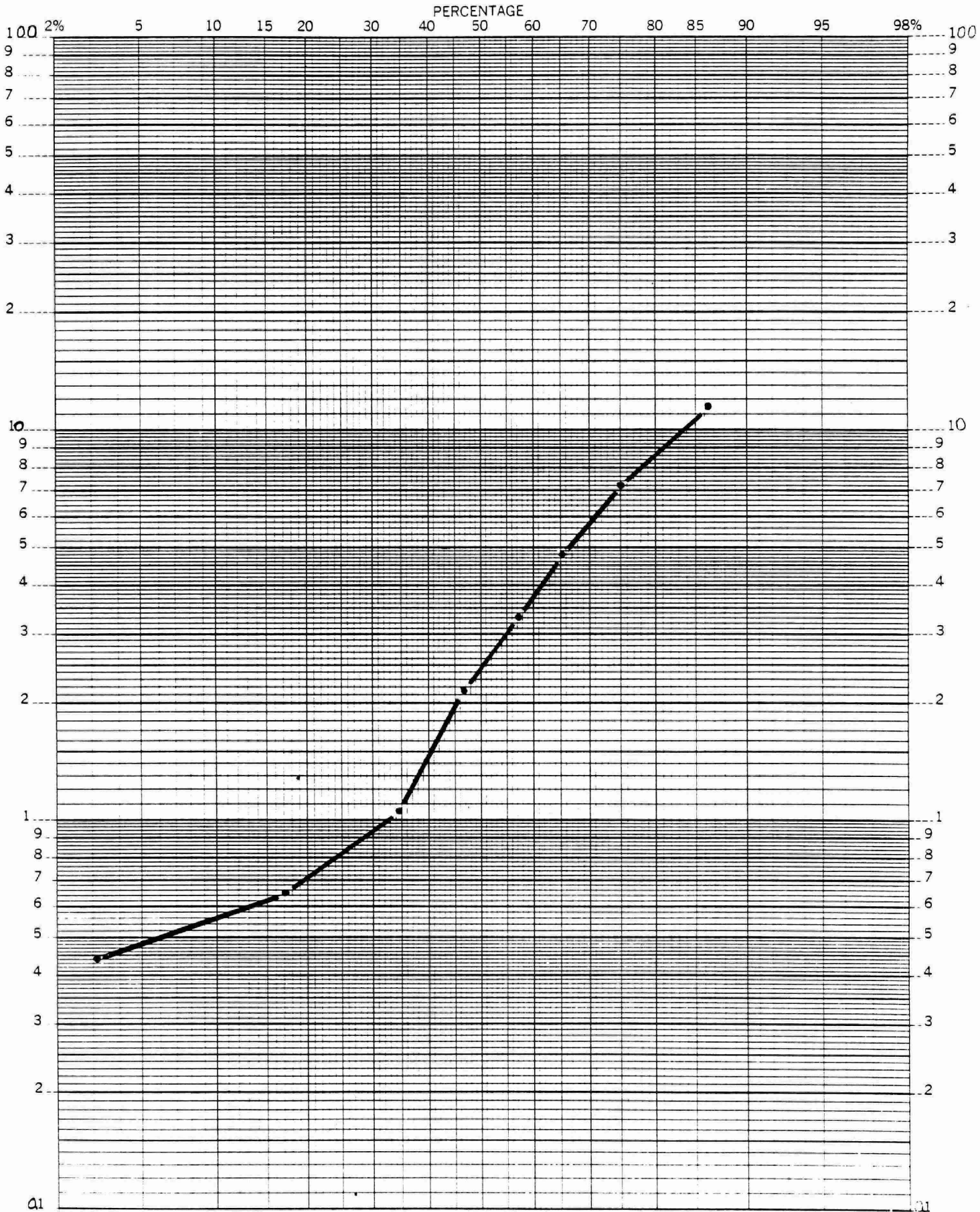


FIGURE No. 7 Particle Size Distribution of Particulate Matter
Emitted by the Stack of the CO Boiler - Test 2

TABLE 7
PARTICLE SIZE DISTRIBUTION OF PARTICULATE MATTER EMITTED
BY THE STACK OF THE CO BOILER - TEST NO. 3

Stage	Weight Collected (mg)	% in Size Range (%)	Cumulative % Less Than Size Range (%)	Size Range (um)	Effective Cut Diameter (um)
0	16.5	21.65	78.35	11.25	11.25
1	5.6	7.35	71.00	7.00 - 11.25	7.00
2	4.8	6.30	64.70	4.70 - 7.00	4.70
3	5.3	6.96	57.74	3.25 - 4.70	3.25
4	7.0	9.19	48.56	2.10 - 3.25	2.10
5	9.2	12.07	36.48	1.03 - 2.10	1.03
6	13.6	17.85	18.64	0.64 - 1.03	0.64
7	11.0	14.44	4.20	0.43 - 0.64	0.43
Filter	3.2	4.20	0.00	0.30 - 0.43	0.30
Total	76.2				

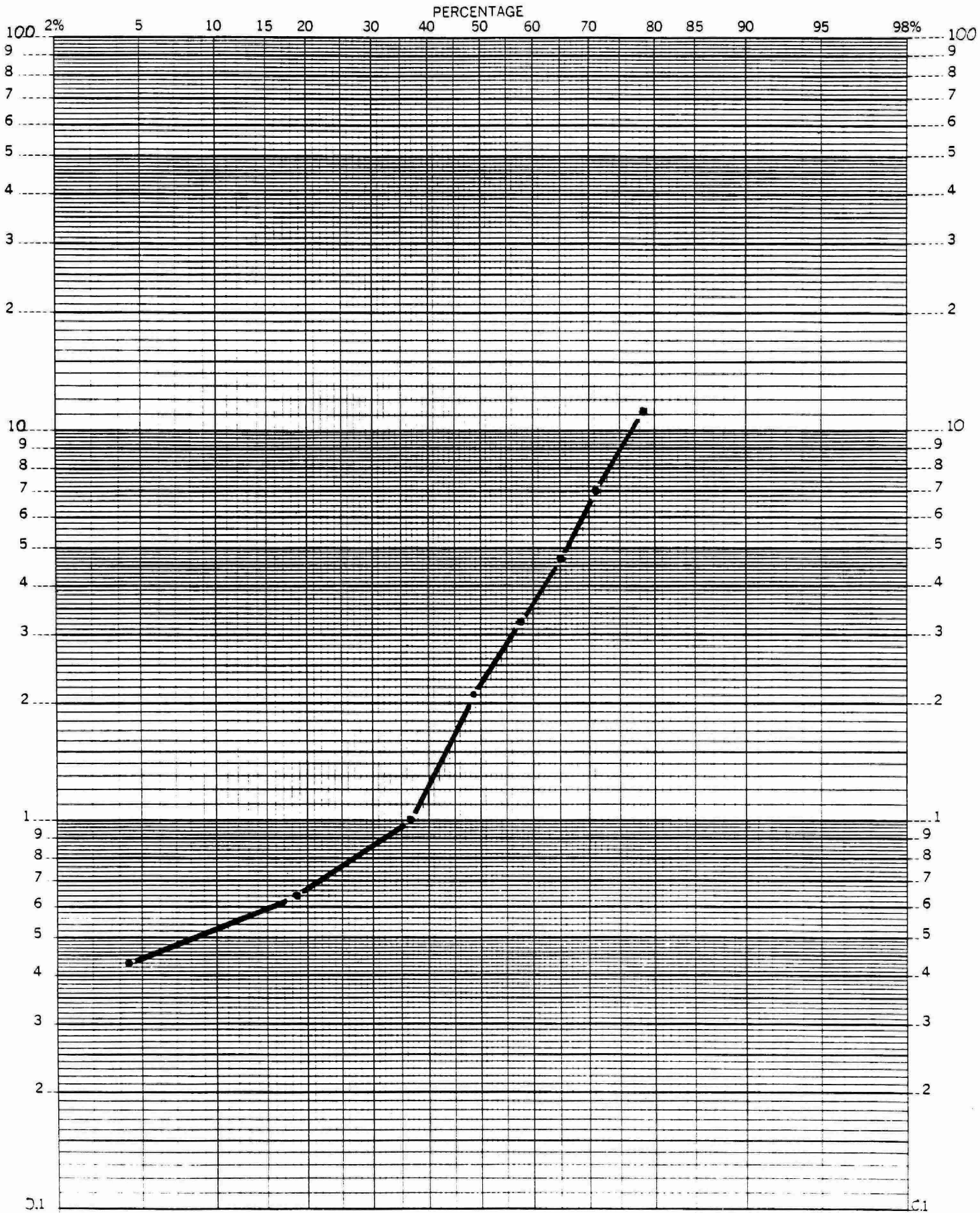


FIGURE No. 8 Particle Size Distribution of Particulate Matter
Emitted by the Stack of the CO Boiler - Test 3

TABLE 8
TRACE ELEMENTS ANALYSIS PERFORMED ON SAMPLES OF PARTICULATE MATTER
FROM THE STACK OF THE CO BOILER
(all weights are in milligrams)

RUN NO.	ELEMENT STAGE	As	Zn	Pb	Cd	Co	Mn	Cr	V	Cu	Sr	Ba	Ni	Fe	Total Stage Weight
1	Washings	0.01	0.771	0.087	0.002	0.012	0.072	0.392	0.069	0.024	0.021	0.029	0.431	2.91	297.8
	Filter	0.185	0.098	0.390	0.002	0.001	0.027	0.063	0.319	0.012	0.211	0.329	0.231	3.67	544.9
	Impingers	0.01	0.063	0.033	0.002	0.001	0.002	0.002	0.040	0.025	0.0004	0.003	0.004	0.086	108.7
	TOTAL	0.185	0.932	0.510	0.006	0.014	0.031	0.457	0.428	0.061	0.2324	0.361	0.666	6.666	951.4
2	Washings	0.01	0.600	0.066	0.001	0.010	0.034	0.302	0.078	0.020	0.017	0.018	0.314	2.29	311.1
	Filter	0.156	0.072	0.355	0.022	0.022	0.012	0.054	0.267	0.009	0.201	0.377	0.188	3.19	378.5
	Impingers	0.01	0.043	0.010	0.0008	0.0003	0.001	0.003	0.001	0.001	0.0004	0.0007	0.005	0.036	41.4
	TOTAL	0.156	0.715	0.431	0.0238	0.0323	0.047	0.359	0.346	0.030	0.2184	0.3957	0.507	5.516	731.0
3	Washings	0.01	0.944	0.052	0.001	0.010	0.035	0.343	0.054	0.014	0.011	0.021	0.333	2.46	195.5
	Filter	0.255	0.137	0.475	0.002	0.030	0.020	0.061	0.902	0.012	0.262	0.474	0.820	4.35	500.0
	Impingers	0.01	0.018	0.008	0.0003	0.0003	0.001	0.0008	0.0002	0.006	0.0001	0.0003	0.004	0.021	73.7
	TOTAL	0.255	1.099	0.535	0.0033	0.0403	0.056	0.4048	0.9562	0.032	0.2731	0.4953	1.157	6.831	769.2
Total average of three runs		0.199+ 0.051	0.915+ 0.193	0.492+ 0.054	0.011+ 0.011	0.029+ 0.013	0.045+ 0.013	0.407+ 0.049	0.577+ 0.331	0.041+ 0.017	0.241+ 0.028	0.417+ 0.070	0.777+ 0.339	6.338+ 0.716	817.2
Coefficient of Variation		19.9	21.0	11.0	101.0	46.7	28.3	12.0	57.4	42.3	11.8	16.7	43.6	11.3	
$C_v = 100 \cdot \frac{G}{\bar{X}}$															
Average Concentration (ppm w)		244+ 62	1120+ 236	602+ 66	13+ 13	35+ 16	55+ 16	498+ 60	706+ 405	50+ 21	295+ 34	510+ 86	951+ 415	7756+ 876	

TABLE 9
TRACE ELEMENTS DISTRIBUTION ON THE PLATES AND FILTER OF THE ANDERSEN COLLECTOR FOR TESTS AT THE STACK OF THE CO BOILER
(all weights are in micrograms)

RUN NO.	ELEMENT PLATE	As	Zn	Pb	Cd	Co	Mn	Cr	V	Cu	Sr	Ba	Ni	Fe	Stage Weight (mg)
1	0	1	12	2	0.2	0.2	0.3	0.6	3	1	0.6	13	3	38	10.0
2		0.1	18	2	0.1	0.1	0.2	1	2	2	0.5	12	2	37	11.6
3		0.1	13	4	0.3	0.2	0.6	1	5	1	1	12	4	63	16.5
1	1	1	10	2	0.1	0.2	0.4	0.6	2	3	0.4	6	3	33	11.7
2		0.1	10	3	0.1	0.1	0.2	2	2	4	0.5	8	3	28	9.8
3		0.1	12	1	0.1	0.1	0.3	3	1	2	0.3	7	3	33	5.6
1	2	1	15	2	0.1	0.1	0.2	0.3	0.5	2	0.2	3	1	17	3.8
2		0.1	11	2	0.1	0.1	0.1	1	1	2	0.4	19.4	2	25	8.1
3		0.1	17	1	0.1	0.1	0.1	0.5	1	2	0.4	31	1	13	4.8
1	3	1	56	3	0.2	0.2	0.3	0.8	1.5	4	0.8	40	3	33	5.3
2		0.1	16	1	0.1	0.1	0.1	0.4	1	2	0.4	21	1	21	7.3
3		0.1	17	1	0.1	0.1	0.1	1	1	1	0.3	8	1	27	5.3
1	4	1	41	2	0.1	0.2	0.2	0.5	2	2	0.5	25	2	35	7.4
2		0.1	8	3	0.1	0.1	0.1	1	2	1	0.4	8	2	25	8.6
3		0.1	15	2	0.1	0.1	0.2	0.5	2	1	0.4	5	2	25	7.0
1	5	1	6	2	0.1	0.1	0.2	0.4	2	1	0.3	9	2	32	8.8
2		0.1	25	2	0.1	0.2	0.2	1	2	2	0.6	34	2	28	10.3
3		0.1	14	2	0.1	0.1	0.1	0.4	2	1	0.5	23	2	23	9.2
1	6	1	6	1	0.1	0.1	0.2	0.4	2	1	0.4	7	2	26	16.1
2		0.1	7	3	0.1	0.3	0.1	1	4	1	0.6	7	4	41	16.2
3		0.1	7	2	0.1	0.2	0.1	1	3	1	0.5	8	3	39	13.6
1	7	1	3	0.4	0.1	0.1	0.1	0.4	1	1	0.4	7	1	12	9.6
2		0.1	20	2	0.1	0.2	0.1	3	2	1	0.3	13	2	34	10.4
3		0.1	13	2	0.1	0.2	0.1	0.4	2	1	0.5	30	3	32	11.0
1	Filter	10	25	27	0.3	1	5	7	10	2	67	82	4	357	1.0
2		10	26	26	0.3	1	5	7	10	2	67	87	4	368	2.7
3		10	29	28	0.3	2	5	7	10	2	68	94	4	396	3.2

TABLE 10
CONCENTRATIONS OF TRACE ELEMENTS (ppm by weight) ON THE PLATES AND FILTER OF THE ANDERSEN COLLECTOR
FOR TESTS AT THE STACK OF THE CO BOILER

Run No.	Element		As	Zn	Pb	Cd	Co	Mn	Cr	V	Cu	Sr	Ba	Ni	Fe	Stage Weight (mg)
	Plate															
1	0	100	1200	200	20	20	30	60	300	100	60	1300	300	3800	10.0	
2		9	1552	172	9	9	17	86	172	172	43	1034	172	3190	11.6	
3		6	788	242	18	12	36	61	303	61	61	727	242	3818	16.5	
1	1	85	855	171	9	17	34	51	171	256	34	513	256	2821	11.7	
2		10	1020	306	10	10	20	204	204	408	51	816	306	2857	9.8	
3		18	2143	179	18	18	54	536	179	357	54	1250	536	5893	5.6	
1	2	263	3947	526	26	26	53	79	132	526	53	789	263	4474	3.8	
2		12	1358	247	12	12	12	123	123	247	49	2395	247	3086	8.1	
3		21	3542	208	21	21	21	104	208	417	83	6458	208	2708	4.8	
1	3	189	10566	566	38	38	57	151	283	755	151	7547	566	6226	5.3	
2		14	2192	137	14	14	14	55	137	274	55	2877	137	2877	7.3	
3		19	3208	189	19	19	19	189	189	189	57	1509	189	5094	5.3	
1	4	135	5541	270	14	27	27	68	270	270	68	3378	270	4730	7.4	
2		12	930	349	12	12	12	116	233	116	47	930	233	2907	8.6	
3		14	2143	286	14	14	29	71	286	143	57	714	286	3571	7.0	
1	5	114	682	227	11	11	23	45	227	114	34	1023	227	3636	8.8	
2		10	2427	194	10	19	19	97	194	194	58	3301	194	2718	10.3	
3		11	1522	217	11	11	11	43	217	109	54	2500	217	2500	9.2	
1	6	62	373	62	6	6	12	25	124	62	25	435	124	1615	16.1	
2		6	432	185	6	19	6	62	247	62	37	432	247	2531	16.2	
3		7	515	147	7	15	7	74	221	74	37	588	221	2868	13.6	
1	7	104	313	42	10	10	10	42	104	104	42	729	104	1250	9.6	
2		10	1923	192	10	19	10	288	192	96	29	1250	192	3269	10.4	
3		9	1182	182	9	18	9	36	182	91	45	2727	273	2909	11.0	
1	Filter	10000	25000	27000	300	1000	5000	7000	10000	2000	67000	82000	4000	357000	1.0	
2		3704	9630	9630	111	370	1852	2593	3704	741	24815	32222	1481	136296	2.7	
3		3125	9063	8750	94	625	1563	2188	3125	625	21250	29375	1250	123750	3.2	
1	All	244	2361	562	18	30	93	149	325	231	958	2605	285	7911	73.7	
2		127	1659	518	13	26	72	205	306	200	832	2463	259	7141	85.0	
3		142	1798	564	17	41	87	194	354	158	944	2861	302	8543	76.2	
Average			171+ 64	1939+ 372	548+ 26	16+ 3	32+ 8	84+ 11	183+ 30	328+ 24	196+ 37	911+ 69	2643+ 202	282+ 22	7865+ 702	78.3+ 5.9
C _v = 100 · $\frac{G}{\bar{X}}$			37.2	19.2	4.7	16.5	24.0	12.9	16.2	7.4	18.7	7.6	7.6	7.7	8.9	7.6

TABLE 11
SUMMARY OF THE SO₂ TESTS AT THE STACK OF THE CO BOILER

RUN No.	Sampling Time (min)	Production Rate (fresh FCCU feed rate) (m ³ /h)	Stack Gas Flowrate (DSCMS)	Volume of Gas Sampled (DSCM)	Concentration		Emission Rate		Emission Factor For The Fresh FCCU Feed Rate	
					Sulphate*	SO ₂	Sulphate*	SO ₂	Sulphate*	SO ₂
					(mg/DSCM)	(mg/DSCM)	(g/s)	(g/s)	(g/DSCM)	(g/DSCM)
1	22	237.2	49.99	0.684	22.1	1293.0	1.11	64.64	16.85	981.0
2	30	236.3	49.12	0.638	32.3	6366.4	1.59	312.72	24.22	4764.2
3	30	237.7	48.35	0.636	29.8	6951.2	1.44	336.09	21.81	5090.1
Average		237.1 ⁺ 0.7 ⁻	49.15 ⁺ 0.82 ⁻	0.653 ⁺ 0.027 ⁻	28.1 ⁺ 5.3 ⁻	4870.2 ⁺ 3111.7 ⁻	1.38 ⁺ 0.25 ⁻	237.82 ⁺ 150.43 ⁻	20.96 ⁺ 3.76 ⁻	3611.8 ⁺ 2284.1 ⁻
Coefficient of Variation		0.3	1.7	4.2	18.9	63.9	17.9	63.3	17.9	63.2

$$C_v = 100 \cdot \frac{\sum \frac{\bar{x}}{x}}{n}$$

* Result possibly in error (see section 4.2)

TABLE 12
SUMMARY OF THE NO_x TESTS AT THE STACK OF THE CO BOILER

RUN No.	Production Rate (fresh FCCU feed rate) (m ³ /h)	Stack Gas Flowrate (DSCMS)	Volume of Gas Sampled* (l)	Concentration as NO ₂ (mg/DSCM)	Emission Rate as NO ₂ (g/s)	Emission Factor for the Fresh FCCU Feed Rate (g/DSCM)	Corrected Emission Factor for the Fresh FCCU Feed Rate** (g/DSCM)
1			1.260	268.0	13.40	203.4	192.4
2	237.2	49.99	1.358	214.1	10.70	162.4	151.4
3			1.340	254.1	12.70	192.7	181.7
4			1.348	412.9	20.28	309.0	298.2
5	236.3	49.12	1.397	265.0	13.02	198.4	187.6
6			1.459	349.8	17.18	261.7	250.9
7			1.502	71.6	3.46	52.4	41.0
8	237.7	48.35	1.450	46.5	2.25	34.1	22.7
9			1.450	138.2	6.68	101.2	89.8
Average	237.1 _{+0.7}	49.15 _{+0.82}	1.396 _{+0.076}	224.5 _{+121.6}	11.08 _{+6.01}	168.4 _{+91.7}	157.3 _{+91.9}
Coefficient of Variation $C_v = 100 \cdot \frac{\bar{S}}{\bar{X}}$	0.3	1.7	5.4	54.2	54.3	54.5	58.4

* Dry at standard conditions

** Corrected by subtracting the contribution of the additional fuel gas burnt in the CO Boiler

TABLE 13
SUMMARY OF THE TESTS PERFORMED AT THE STACK OF THE CO BOILER

RUN No.	Production Rate (fresh FCCU feed rate) (m ³ /h)	Stack Gas Velocity [†] (m/s)	Stack Gas Flowrate (DSCMS)	Concentration				Part. Matter (g/s)	Emission Sulphate* (g/s)	Rate SO ₂ (g/s)	NO ₂ (g/s)	Emission Factor for Fresh FCCU Feed Rate			
				Part. Matter (mg/DSCM)	Sulphate* (mg/DSCM)	SO ₂ (mg/DSCM)	NO ₂ (mg/DSCM)					Part. Matter (g/m ³)	Sulphate* (g/m ³)	SO ₂ (g/m ³)	NO ₂ (g/m ³)
1	237.2	7.2	49.99	242.7	22.1	1293.0	245.4	12.14	1.11	64.64	12.3	184.25	16.85	981.0	186.2
2	236.3	7.1	49.12	202.3	32.3	6366.4	342.6	9.94	1.59	312.72	16.8	151.43	24.22	4764.2	256.4
3	237.7	7.1	48.35	205.3	29.8	6951.2	85.4	9.93	1.44	336.09	4.13	150.39	21.81	5090.1	62.6
Average	237.1+ 0.7	7.1+ 0.1	49.15+ 0.82	216.8+ 22.5	28.1+ 5.3	4870.2+ 3111.7	224.5+ 121.6	10.67+ 1.27	1.38+ 0.25	237.82+ 150.43	11.1+ 6.0	162.03+ 19.25	20.96+ 3.76	3611.8+ 2284.1	168.4+ 91.7
Coefficient of Variation $C_v = 100 \cdot \frac{\sum X}{X}$	0.3	0.7	1.7	10.4	18.9	63.9	54.2	11.9	17.9	63.3	54.3	11.9	17.9	63.2	54.5

[†] Actual conditions

* Result possibly in error (see section 4.2)

TABLE 14

SUMMARY OF THE PARTICULATE MATTER TESTS AT THE STACK OF THE NO. 1 POWER BOILER

(Fuel: No. 6 Fuel Oil)

Test No.	Sampling Time (min)	Stack Temperature (°C)	Relative Humidity (%)	Fuel Burning Rate (t/h)	Volume of Gas Sampled (DSCM)	Stack Gas Velocity* (m/s)	Stack Gas Flowrate (DSCMS)	Concentration (mg/DSCM)	Emission Rate (g/s)	Average Isokinetics %I	Emission Factor (g/t)
1	160	180	9.82	5.32	3.269	6.2	20.22	47.30	0.957	96.7	647.4
2	160	187	9.99	5.44	3.413	6.9	21.98	44.72	0.984	95.4	650.9
3	160	188	10.01	5.10	3.372	6.5	22.85	45.74	1.046	96.7	738.0
Average	160	185 ⁺ ₅ ⁻	9.94 ⁺ _{0.10} ⁻	5.29 ⁺ _{0.17} ⁻	3.351 ⁺ _{0.074} ⁻	6.5 ⁺ _{0.4} ⁻	21.68 ⁺ _{1.34} ⁻	45.92 ⁺ _{1.30} ⁻	0.995 ⁺ _{0.046} ⁻	96.3 ⁺ _{0.8} ⁻	678.8 ⁺ _{51.3} ⁻
Coefficient of Variation $C_V = 100 \cdot \frac{\bar{S}}{\bar{X}}$	0	2.5	1.1	3.3	2.2	5.4	6.2	2.8	4.6	0.8	7.6

* Actual conditions

TABLE 15

TRACE ELEMENTS ANALYSIS PERFORMED ON SAMPLES OF PARTICULATE MATTER
FROM THE STACK OF THE NO. 1 POWER BOILER
(all weights are in milligrams)(Fuel: No. 6 Fuel Oil)

RUN NO.	ELEMENT STAGE	As	Zn	Pb	Cd	Co	Mn	Cr	V	Cu	Sr	Ba	Ni	Fe	Total Stage Weight
1	Washings	0.0018	0.420	0.043	0.002	0.0038	0.020	0.169	0.108	0.020	0.004	0.009	0.279	1.14	34.5
	Filter	0.126	0.157	0.236	0.001	0.016	0.021	*	2.35	0.017	0.210	0.363	0.820	4.34	120.1
	Impingers	0.0008	0.014	0.004	0.0019	0.0006	0.0008	0.001	0.0004	0.003	0.0003	0.0004	0.0008	0.025	9.5
	TOTAL	0.1286	0.591	0.283	0.0049	0.0204	0.0418	0.170	2.4584	0.040	0.2143	0.3724	1.0998	5.505	164.1
2	Washings	0.001	0.418	0.048	0.002	0.003	0.016	0.117	0.084	0.015	0.003	0.008	0.230	0.954	29.1
	Filter	0.125	0.170	0.235	0.001	0.019	0.021	*	2.11	0.017	0.209	0.228	2.38	4.04	123.5
	Impingers	0.0008	0.020	0.004	0.0003	0.0004	0.0004	0.0006	0.0003	0.003	0.0001	0.0002	0.0008	0.015	10.8
	TOTAL	0.1268	0.608	0.287	0.0033	0.0224	0.0374	0.1176	2.1943	0.035	0.2121	0.2362	2.6108	5.009	163.4
3	Washings	0.002	0.573	0.031	0.003	0.005	0.019	0.114	0.134	0.019	0.004	0.009	0.301	1.28	52.0
	Filter	0.071	0.121	0.173	0.001	0.013	0.012	*	1.73	0.012	0.160	0.281	1.78	2.40	102.2
	Impingers	0.0008	0.008	0.003	0.0001	0.0004	0.0004	0.0007	0.0002	0.002	0.0001	0.0004	0.0006	0.014	18.3
	TOTAL	0.0738	0.702	0.207	0.0041	0.0184	0.0314	0.1147	1.8642	0.033	0.1641	0.2904	2.0816	3.694	172.5
Total Average of three runs		0.1097+ 0.0311	0.6337+ 0.0598	0.259+ 0.045	0.0041+ 0.0008	0.0204+ 0.0020	0.0369+ 0.0052	0.1341+ 0.0311	2.1723+ 0.2977	0.036+ 0.004	0.1968+ 0.0284	0.2997+ 0.0685	1.9307+ 0.7667	4.736+ 0.936	166.7
Coefficient of Variation $C_v = 100 \frac{\sum}{\bar{X}}$		28.4	9.4	17.4	19.5	9.8	14.2	23.2	13.7	10.0	14.4	22.9	39.7	19.8	
Average Concentration (ppm w)		658+ 187	3802+ 359	1554+ 270	25+ 5	122+ 12	221+ 31	805+ 187	13034+ 1786	216+ 22	1181+ 170	1798+ 411	11584+ 4600	28416+ 5615	

* Blank unreliable

TABLE 16

TRACE ELEMENTS CONCENTRATION OF DIFFERENT SUBSTANCES
(concentrations expressed as ppm w)

ELEMENT SOURCE	As	Zn	Pb	Cd	Co	Mn	Cr	V	Cu	Sr	Ba	Ni	Fe
Crude Oil (Alberta Cretaceous) ⁷	0.0024	0.670	-	-	0.0027	0.048	-	0.682	-	-	-	0.609	0.696
No. 1 Power Boiler Emissions	658+ 187	3082+ 359	1554+ 270	25+ 5	122+ 12	221+ 31	805+ 187	13034+ 1786	216+ 22	1181+ 170	1798+ 411	11584+ 4600	28416+ 5615
CO Boiler Emissions (a)	244+ 62	1120+ 236	602+ 66	13+ 13	35+ 16	55+ 16	498+ 60	706+ 405	50+ 21	295+ 34	510+ 86	951+ 415	7756+ 876
CO Boiler Emissions (b)	171+ 64	1939+ 372	548+ 26	16+ 3	32+ 8	84+ 11	183+ 30	328+ 34	196+ 37	911+ 69	2643+ 202	282+ 22	7865+ 702
Regenerated Used Catalyst	0.1	21	100	0.3	20	-	47	520	8	-	-	300	2100

(a) Results from tests for total particulate matter.

(b) Results from tests for particle size distribution.

TABLE 17

SUMMARY OF THE SO₂ TESTS AT THE STACK OF THE NO. 1 POWER BOILER
(Fuel: No. 6 Fuel Oil)

Run No.	Sampling Time (min)	Burning Rate (t/h)	Stack Gas Flowrate (DSCMS)	Volume of Gas Sampled (DSCM)	Concentration		Emission Rate		Emission Factor	
					Sulphate* (mg/DSCM)	SO ₂ (mg/DSCM)	Sulphate* (g/s)	SO ₂ (g/s)	Sulphate* (kg/t)	SO ₂ (kg/t)
1	31	5.32	20.22	0.645	154.6	2600.2	3.13	52.58	2.12	35.58
2	30	5.44	21.98	0.609	30.3	2620.5	0.67	57.60	0.44	38.12
3	30	5.10	22.85	0.643	35.4	2759.6	0.81	63.06	0.57	44.51
Average	30.3 [±] _{0.6}	5.29 [±] _{0.17}	21.68 [±] _{1.34}	0.632 [±] _{0.020}	73.4 [±] _{70.3}	2660.1 [±] _{86.8}	1.53 [±] _{1.38}	57.74 [±] _{5.24}	1.04 [±] _{0.93}	39.40 [±] _{4.60}
Coefficient of Variation	1.9	3.3	6.2	3.1	95.8	3.3	90.0	9.1	89.2	11.7

$$C_v = 100 \frac{\sum x^2}{n \bar{x}^2}$$

* Result possibly in error (see section 4.2)

TABLE 18

SUMMARY OF THE NO_x TESTS AT THE STACK OF THE NO. 1 POWER BOILER
(Fuel: No. 6 Fuel Oil)

Run No.	Fuel (oil) Burning Rate (t/h)	Stack Gas Flowrate (DSCMS)	Volume of Gas Sampled* (l)	Concentration as NO ₂ (mg/DSCM)	Emission Rate as NO ₂ (g/s)	Emission Factor For Oil Fuel (kg/t)
1			1.403	668.6	13.52	9.15
2	5.32	20.22	1.352	514.7	10.41	7.04
3			1.366	747.4	15.11	10.22
4			1.528	448.8	9.86	6.53
5	5.44	21.98	1.388	802.2	17.63	11.67
6			1.410	797.4	17.53	11.60
7			1.387	824.8	18.85	13.31
8	5.10	22.85	1.433	793.7	18.14	12.80
9			1.495	840.7	19.21	13.56
Average	5.29 ⁺ 0.17 ⁻	21.68 ⁺ 1.34 ⁻	1.418 ⁺ 0.059 ⁻	715.4 ⁺ 142.6 ⁻	15.58 ⁺ 3.58 ⁻	10.65 ⁺ 2.61 ⁻
Coefficient of Variation $C_v = 100 \cdot \frac{S}{\bar{X}}$	3.3	6.2	1.4	19.9	22.9	24.5

* Dry at standard conditions

TABLE 19

SUMMARY OF THE NO_x TESTS AT THE STACK OF THE NO. 1 POWER BOILER
(Fuel: Refinery Fuel Gas)

Run No.	Fuel (gas) Burning Rate (m ³ /h)	Stack Gas Flowrate (DSCMS)	Volume of Gas Sampled* (l)	Concentration as NO ₂ (mg/DSCM)	Emission Rate as NO ₂ (g/s)	Emission Factor For Gas Fuel (g/10 ³ m ³)
1			1.322	276.7	6.32	4.70
2	4.843	22.85	1.427	254.8	5.82	4.33
3			1.395	258.1	5.90	4.39
4			1.416	273.6	6.25	4.65
5	4.843	22.85	1.395	287.2	6.56	4.88
6			1.425	229.2	5.24	3.90
7			1.444	272.3	6.22	4.62
8	4.843	22.85	1.398	276.6	6.32	4.70
9			1.348	603.3	13.79	10.25
Average	4.843	22.85	1.397 ⁺ 0.039 ⁻	303.5 ⁺ 113.7 ⁻	6.94 ⁺ 2.60 ⁻	5.16 ⁺ 1.93 ⁻
Coefficient of Variation $C_v = 100 \cdot \frac{\bar{S}}{\bar{X}}$	0	0	2.8	37.5	37.5	37.5

* Dry at standard conditions

TABLE 20
SUMMARY OF THE TESTS PERFORMED AT THE STACK OF THE NO. 1 POWER BOILER

Run No.	Fuel Burning Rate (t/h)	Stack Gas Velocity** (m/s)	Stack Gas Flowrate (DSCMS)	Concentration				Emission Rate				Emission Factor			
				Part. Matter (mg/DSCM)	Sulphate*** (mg/DSCM)	SO ₂ (mg/DSCM)	NO ₂ (mg/DSCM)	Part. Matter (g/s)	Sulphate*** (g/s)	SO ₂ (g/s)	NO ₂ (g/s)	Part. Matter (g/t)	Sulphate*** (kg/t)	SO ₂ (kg/t)	NO ₂ (kg/t)
1	5.32a)	6.2	20.22	47.30	154.6	2600.2	643.6	0.957	3.13	52.58	13.01	647.4	2.12	35.58	8.80
2	5.44a)	6.9	21.98	44.72	30.3	2620.5	682.8	0.984	0.67	57.60	15.01	650.9	0.44	38.12	9.93
3	5.10a)	6.5	22.85	45.74	35.4	2759.6	819.7	1.046	0.81	63.06	18.73	738.0	0.57	44.51	13.22
Average	5.29 _{+0.17}	6.5 _{+0.4}	21.68 _{+1.34}	45.92 _{+1.30}	73.4 _{+70.3}	2660.1 _{+86.8}	715.4 _{+142.6}	0.995 _{+0.046}	1.53 _{+1.38}	57.74 _{+5.24}	15.58 _{+3.58}	678.8 _{+51.3}	1.04 _{+0.93}	39.40 _{+4.60}	10.65 _{+2.61}
Coefficient of Variation*	3.3	5.4	6.2	2.8	95.8	3.3	19.9	4.6	90.0	9.1	22.9	7.6	8912	11.7	24.5
1	4.843b)	-	22.85	-	-	-	263.2	-	-	-	6.01	-	-	-	4.47c)
2	4.843b)	-	22.85	-	-	-	263.3	-	-	-	6.02	-	-	-	4.48c)
3	4.843b)	-	22.85	-	-	-	384.1	-	-	-	8.78	-	-	-	6.52c)
Average	4.843	-	22.85	-	-	-	303.5 _{+113.7}	-	-	-	6.94 _{+2.60}	-	-	-	5.16 _{+1.93}
Coefficient of Variation*	0		0	-	-	-	37.5	-	-	-	37.5	-	-	-	37.5

- * Coefficient of variation $C_v = 100 \cdot \frac{\bar{S}}{\bar{X}}$
- ** Actual conditions
- *** Result possibly in error (see section 4.2)

- a) tonnes of No. 6 Fuel Oil per hour
- b) cubic meters of refinery fuel gas per hour
- c) grams per thousand cubic meters of fuel

TABLE 21

COMPARISON OF EMISSION RATES AND EMISSION FACTORS (CALCULATED PER MJ
OF HEAT IN THE STEAM PRODUCED) FOR THE TWO BOILERS SAMPLED

Source	Heat Produced (M /sec)	Particulate (g/s)	Emission Rate			Particulate (g/MJ)	Emission Factor		
			Sulphate* (g/s)	Sulphur Dioxide (g/s)	Nitrogen Oxides (g/s)		Sulphate* (g/MJ)	Sulphur Dioxide (g/MJ)	Nitrogen Oxides (g/MJ)
FCCU - CO Boiler Addnl fuel: Refinery Gas	81.006	10.67	1.38	237.82	11.1	0.132	0.017	2.936	0.137
No. 1 Power Boiler Fuel: Refinery gas	55.924	-	-	-	6.94	-	-	-	0.124
No. 1 Power Boiler Fuel: No. 6 Fuel Oil	58.539	1.08	1.53	57.74	15.58	0.018	0.026	0.986	0.266

* Result possibly in error (see section 4.2)

TABLE 22
SUMMARY OF THE SO₂ TESTS AT THE STACK OF THE SULPHUR RECOVERY UNIT

Run No.	Sampling Time (min)	Stack Temp. (°C)	Relative Humidity (%)	Stack Gas Velocity* (m/s)	Stack Gas Flowrate (DSCMS)	Volume of Gas Sampled (DSCM)	Concentration		Emission Rate		Emission Factor**	
							Sulphate*** (mg/DSCM)	SO ₂ (mg/DSCM)	Sulphate*** (g/s)	SO ₂ (g/s)	Sulphate*** (kg/t)	SO ₂ (kg/t)
1	13	354	16.44	6.86	1.79	0.209	2110.7	22279	3.78	39.86	25.10	264.9
2	15	360	17.67	6.88	1.75	0.228	188.7	36427	0.33	63.79	2.20	424.0
3	15	399	18.36	6.89	1.64	0.244	451.5	31823	0.74	52.13	4.92	346.5
Average	14.3+ 1.2-	371+ 24-	17.49+ 0.97-	6.87+ 0.01-	1.73+ 0.08-	0.227+ 0.018-	917.0+ 1042.1-	30176+ 7216-	1.62+ 1.88-	51.93+ 11.97-	10.74+ 12.51-	345.1+ 79.5-
Coefficient of Variation $C_v = 100 \cdot \frac{\bar{S}}{\bar{X}}$	8.1	6.5	5.6	0.2	4.6	7.7	113.6	23.9	116.5	23.0	116.5	23.0

* Actual conditions

** Based on Texaco's estimate of the production level - 13 t sulphur/day

*** Result possibly in error (see section 4.2)

TABLE 23
SUMMARY OF H₂S TESTS AT THE STACK OF THE SULPHUR RECOVERY UNIT

Run No.	Sampling Time (min)	Stack Temp. (°C)	Relative Humidity %	Stack Gas Flowrate (DSCMS)	Volume of Gas Sampled (DSCM)	Concentration (mg/DSCM)	Emission Rate (mg/s)	Emissions Factor* (g/t)
1	12	354	16.26		0.207	0.966	1.64	10.9
2	12	377	17.76	1.70	0.193	1.868	3.17	21.1
3	12	406	18.86		0.193	1.447	2.46	16.3
Average	12	379+ 26	17.63+ 1.31	-	0.198+ 0.008	1.427+ 0.451	2.42+ 0.77	16.1+ 5.1
Coefficient of Variation $C_v = 100 \cdot \frac{\bar{S}}{\bar{X}}$	0	6.8	7.4	-	4.1	31.6	31.6	31.6

* Based on Texaco's estimate of the production level - 13 t sulphur/day



96936000009366